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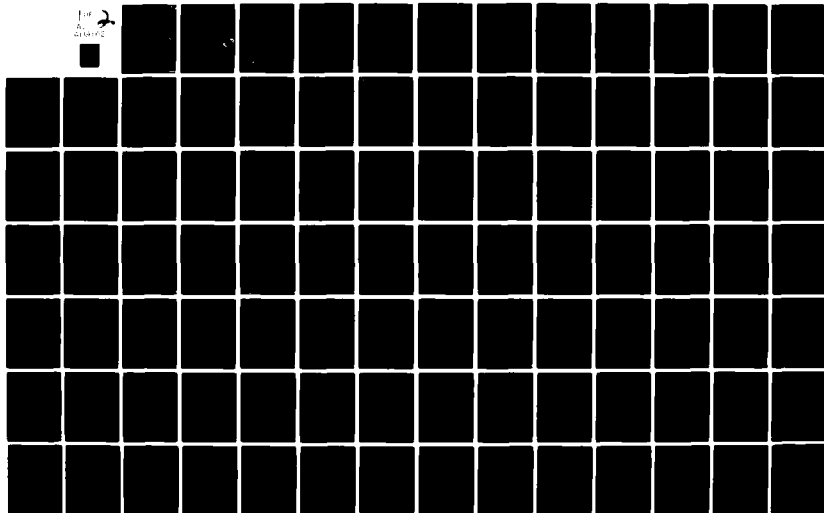
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Report No. 5088

**Understanding Instructions:
The Role of Explanatory Material
Technical Report No. 1**

E.E. Smith and L. Goodman

July 1982

Prepared for:
Office of Naval Research
Psychological Sciences Division

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ONR-TR-1 - /	2. GOVT ACCESSION NO. AD-A119162	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Understanding Instructions: The Role of Explanatory Material		5. TYPE OF REPORT & PERIOD COVERED Technical Report 10/15/80 thru 7/15/82
7. AUTHOR(s) Edward E. Smith and Lorraine Goodman		6. PERFORMING ORG. REPORT NUMBER BBN Report No. 5088
9. PERFORMING ORGANIZATION NAME AND ADDRESS BOLT BERANEK AND NEWMAN INC. 10 Moulton Street Cambridge, Massachusetts 02238		8. CONTRACT OR GRANT NUMBER(s) N00014-81-C-0019
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 458) Arlington, Virginia 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 154-461
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 31 July 1982
		13. NUMBER OF PAGES 102 pages
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Understanding instructions, Executing instructions, Memory for instructions, Troubleshooting, Hierarchical organization, Structural explanation, Functional explanation.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This research deals with how people understand, execute, remember, and use written instructions. The issue of major concern is the organization of steps in a set of instructions. Typically, instructional steps are organized linearly, i.e., instructions consist entirely of a sequence of steps to be executed. Theoretical considerations based on text-processing		

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research, however, suggest that performance would be better if instructions also included some higher-level, hierarchically-organized, explanatory material, where such material serves as a rationale for each executable step. To test this, three different sets of instructions for assembling an electrical circuit were composed. One contained the typical linear organization (Linear instructions), another contained the steps plus explanatory material that emphasized structure (Structural instructions), and a third contained the steps plus explanatory material that emphasized function (Functional instructions). In two experiments, the subjects major tasks were to: (1) read and execute each step, (2) then answer questions about the circuit, and (3) either verbally recall the instructional steps (Experiment 1), or reconstruct the circuit with no instructions present (Experiment 2). In Experiment 1, steps were read faster, executed somewhat more accurately, and recalled more accurately with Structural and Functional instructions than with Linear ones. Experiment 2 replicated the reading-speed and execution-accuracy advantages for the Structural and Functional instructions, and also suggested that Functional instructions might be superior to Structural ones with regard to answering the conceptual-troubleshooting questions about the circuit and reconstructing the circuit.

A secondary concern of the research has been with the content of specific steps. Typically, the time needed to read and to execute a step increased with the number of kernel ideas or propositions in the steps. In addition, steps differ in importance (the more important ones involving major components or their interconnections). While importance affects both reading time and recall, it had no effect on execution, the latter being sensitive primarily to manual requirements.



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UNDERSTANDING INSTRUCTIONS:
THE ROLE OF EXPLANATORY MATERIAL

Edward E. Smith and Lorraine Goodman

Bolt Beranek and Newman Inc.

Report No. 5088

Technical Report No. 1

July 1982

Running Head: Understanding Instructions

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The research described herein was supported by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-81-C-0019, Contract Authority Identification Number NR-154-461.

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TABLE OF CONTENTS

	Page
1. INTRODUCTION	1
1.1 Understanding as explanation	1
1.2 Rationale for the present work	5
2. EXPERIMENT 1	7
2.1 The instructions	7
2.1.1 Linear instructions	7
2.1.2 Hierarchical instructions	10
2.1.3 Propositional nature of the instructional steps	13
2.2 Procedure	16
2.2.1 Overview	16
2.2.2 Stage 1: Self ratings	16
2.2.3 Stage 2: Reading span	16
2.2.4 Stage 3: Instructions task	17
2.2.5 Stage 4: Question-answering	20
2.2.6 Stage 5: Recall	21
2.2.7 Summary	21
2.3 Subjects	21
2.4 Results: Preliminary	21
2.5 Results due to organization of steps	23
2.5.1 Reading times	23
2.5.2 Execution times and errors	28
2.5.3 Recall percentages	31
2.6 Determinants of the Hierarchical advantage	32
2.6.1 Summary of major results	32
2.6.2 Prior activation	35
2.6.3 Chunking	37
2.6.4 Summary	40
2.7 Results due to specific steps	42
2.7.1 Reading times	42
2.7.2 Execution times	49
2.7.3 Percentage recall	51
2.7.4 Summary	56

3. EXPERIMENT 2	59
3.1 Rationale	59
3.2 The instructions	60
3.3 Procedure	60
3.3.1 Overview	60
3.3.2 Stage 1: Self-ratings	60
3.3.3 Stage 2: Instructions task	60
3.3.4 Stage 3: Question-answering	60
3.3.5 Stage 4: Reconstruction	61
3.4 Subjects	61
3.5 Results: Preliminaries	62
3.6 Results due to organization of steps	62
3.6.1 Reading times	62
3.6.2 Execution times and errors	65
3.6.3 Question-answering	65
3.6.4 Reconstruction	68
3.7 Determinants of the Hierarchical advantage	69
3.8 Results due to specific steps	71
3.8.1 Reading times	71
3.8.2 Execution times	75
3.8.3 Summary	75
 4. CONCLUSIONS AND DISCUSSION	 79
4.1 Benefits of explanatory material: Hierarchical advantages	79
4.1.1 Reading times	79
4.1.2 Execution times and accuracy	82
4.1.3 Questions answering	85
4.1.4 Memory	86
4.2 Effects due to specific steps	88
 5. REFERENCES	 91
 APPENDIX A. COMPLETE LISTINGS OF LINEAR, STRUCTURAL AND FUNCTIONAL INSTRUCTIONS USED IN EXPERIMENT 1	 93

1. INTRODUCTION

1.1 Understanding as explanation

In the last few years there has been a veritable explosion of research on the understanding and retention of text, particularly of fictional texts. Some of this research has tried to tackle the question of what it means to understand a line of text. One interesting answer is that understanding a story line describing a particular action amounts to explaining why the character(s) performed that action (e.g., Schank & Abelson, 1977; Wilensky, 1978). If understanding is truly based on explanation, a text will be readable to the extent that the actions described in each of its lines can be readily explained by information the reader already knows (either gleaned from the text itself or accessed from his general experience).

Our concern is with instructional texts, not fictional ones, but the importance of explanation-based understanding may be at least as great in our domain as it is in the story domain. For many instructions, particularly those for assembling a device, are written as a sequence of linear steps ("First do this, then do that, . . ."), with no attempt to provide the reader any explanation of why each step is to be performed. This paucity of explanation may account for why so many readers of assembly instructions have trouble understanding and executing some steps, trouble remembering the instructions if they have to perform the

required operations without an instructional manual, and trouble "debugging" a faulty assembly based on the instructions. To the extent that the above ideas are correct -- that understanding is explanation-based and that most instructions contain little in the way of explanation -- we should be able to improve people's ability to understand, execute, and remember instructional steps by adding some explanatory material to the sequence of steps.

To appreciate how explanatory material can be added to standard instructions, consider Figure 1. The left side contains part of some standard instructions on how to change a flat tire; we refer to these as Linear instructions because, aside from stating a single top-level goal ("Replace a flat tire"), they contain only a sequence of linear steps. If you can put yourself in the situation of a novice driver with little mechanical sophistication, perhaps you can appreciate that these Linear instructions can be difficult to understand. Our novice knows that he needs to get the damaged wheel off but the first step tells him to get a screwdriver: how can a screwdriver help him get the wheel off? Our novice needs some explanation here -- something like:

"You want to get the wheel off, but its bolted to the rim, so you first need to slacken the bolts, but they're behind the hubcap, so you first have to get that off, and that's why you need a screwdriver."

Thus, an explanation of the need for a screwdriver is the goal of removing the hubcap, an explanation of removing the hubcap is the

Linear

Hierarchical

How to Replace a Flat Tire

How to Replace a Flat Tire

- i Get a screwdriver
- ii Use it to pry off the hubcap
- iii Get a wrench
- iv Use it to loosen the bolts that hold the wheel onto the rim
- v Get a jack
- vi Place it under the car on the side of the damaged wheel
- vii Raise the car

- A. The first goal is to remove the damaged wheel
 - (1) To accomplish this, you need to slacken the bolts that hold the wheel onto the rim
 - a Before you can accomplish the latter, you need access to the bolts
 - i Get a screwdriver
 - ii Use it to pry off the hubcap
 - b Now you can loosen the bolts
 - i Get a wrench
 - ii Use it to loosen the bolts
 - (2) To get the damaged wheel off, you need to raise the car high enough to pull the wheel off
 - a To raise the car, use a jack
 - i Get a jack
 - ii Place it under the car on the side of the damaged wheel
 - iii Raise the car

Figure 1. Examples of Linear and Hierarchical instructions for changing a flat tire.

goal of gaining access to the bolts, and an explanation of gaining access to the bolts is the goal of removing the damaged wheel. (We assume that even a novice requires no explanation of why he needs to remove the damaged wheel; i.e., we assume our novice has a schema for replacing a defective component, where part of this schema states that the defective component must be removed.) The needed explanations, or goal statements, have been added to the standard instructions on the righthand side of Figure 1. Since these explanations are at a higher level than the actual steps, the entire set of instructions now has the structure of a hierarchy, and we refer to them as Hierarchical instructions.

Another way to look at the explanatory material in Figure 1 is as constituting a schema for changing a flat. Now any beneficial effect of the explanatory material on our novice's understanding of the steps would be attributed to his processing the steps as an instantiation of a schema. While there may be some important theoretical differences between viewing the explanatory material as a schema and as a source of goal-based explanations, for now we will treat the two views as equivalent, sometimes using schema terminology to describe our manipulations and other times talking in terms of goals.

1.2 Rationale for the present work

The fix-a-flat instructions in Figure 1 are terribly simple. Our concern is with more complex instructions, specifically those for assembling an electrical circuit of the type found in a flashlight. With such instructions one needs to consider not only whether explanatory material is present but also the kind of explanation used. Perhaps the most important difference in kind is that between structure and function (Stevens & Steinberg 1981). Structural explanatory material would deal with the components of the circuit and their interconnections, while functional explanatory material would emphasize the dynamics of current flow.

The present experiments dealt with two major questions regarding explanatory material. First, does the addition of such explanatory material, independent of its type, facilitate the understanding and execution of instructions for assembling an electrical circuit? That is, are hierarchical instructions generally more effective than linear ones? Second, are there differences between structural and functional explanatory material in their specific effects on understanding and execution? In addition to these questions, we were also concerned with effects due to the specific content of instructional steps; discussion of these concerns, however, is best left until we have described our instructions task in detail.

Report No. 5088

Bolt Beranek and Newman Inc.

2. EXPERIMENT 1

2.1 The instructions

The instructions of interest were for assembling an electrical circuit that was part of an electronics kit for teenagers. The circuit was to be constructed on a 3" x 5" plastic console, and the major components included a battery, an on-off switch, and a light bulb.

2.1.1 Linear instructions

The instructions, with minimal explanatory material, are shown in abbreviated form on the lefthand side of Figure 2, where they are referred to as Linear instructions. The first two sentences, which are the only explanatory statements in the Linear instructions, spell out the general goal and procedure of the task. In their full version, they read:

- I. "You will construct an electrical circuit that will light a small lamp when you press a switch."
- II. "The components of the circuit will be installed in the yellow, plastic console."

The remaining sentences, all 34 of them, correspond to executable steps. Even though the 34 steps actually occurred in a continuous sequence in the Linear instructions, it is convenient to discuss them in chunks.

Steps 1-7 deal with assembling the battery connections. The

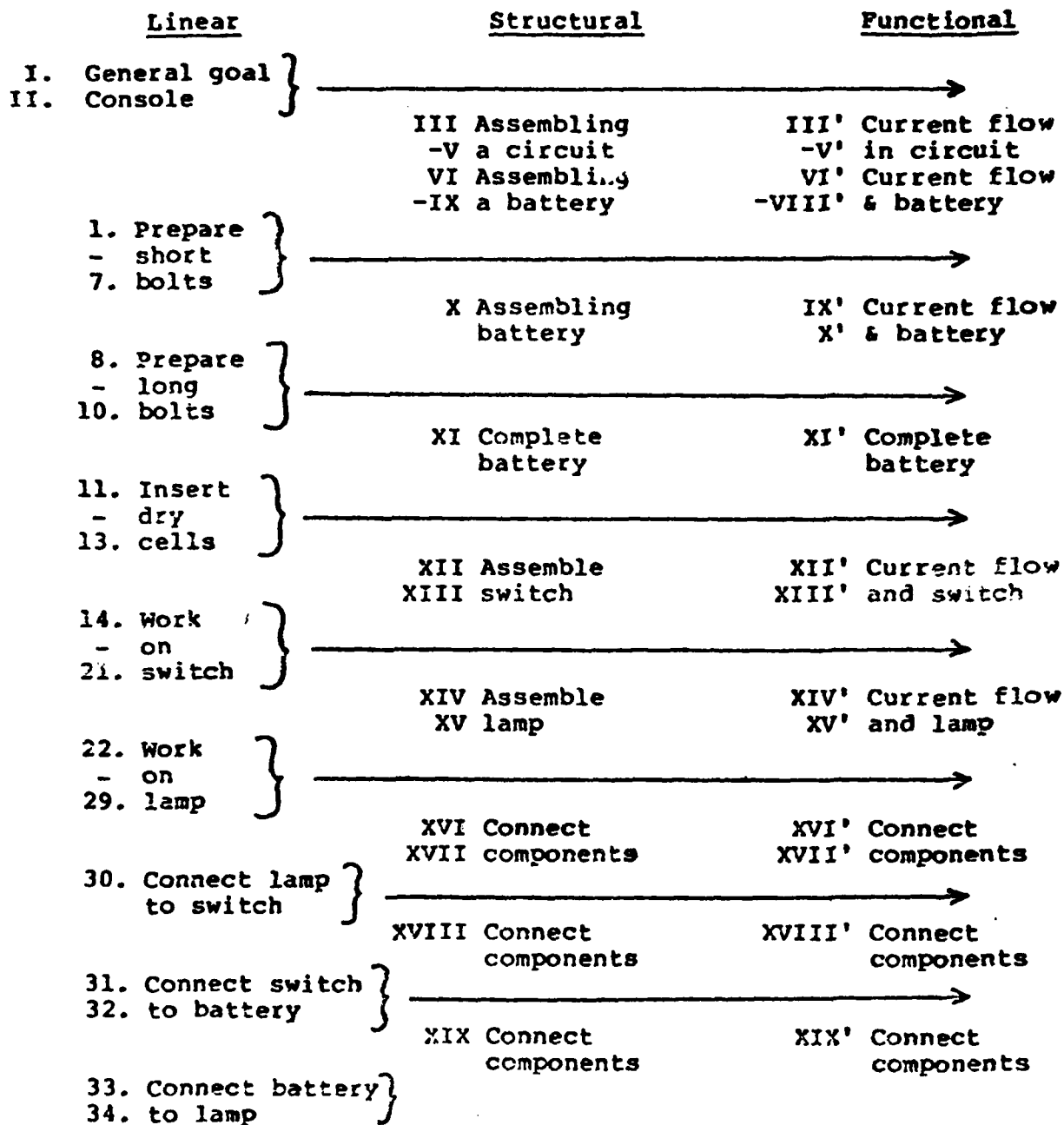


Figure 2. Three types of instructions for assembling an electrical circuit.

first step requires locating the correct wire, while the next two involve wiring together two short bolts. To illustrate, Step 2 reads:

2. "Now you are to wrap one end of the wire around one of the short bolts."

The remaining four steps in this chunk -- Steps 4-7 -- involve placing the bolts in certain grooves of the console so that the bolts can later be connected to dry cells.

The next chunk includes Steps 8-10. These steps also deal with assembling the battery, and require placing two more bolts in other grooves of the console. Step 9 is perhaps the most important:

9. "Place the bolts into the two grooves on the outer edge of the dry cell holder so that the bolt heads face inward."

Steps 11-13 comprise the third chunk. These steps involve inserting the dry cells into the appropriate spaces in the console, thereby completing the battery assembly. Step 12 is probably the most important:

12. "Snap each cell into the holder so one cell's positive pole, and the other's negative, point in the same direction."

The next chunk encompasses Steps 14-21, and involves assembling the on-off switch. The key steps here include placing two bolts through appropriate holes of the console, where one bolt is used to mount the switch to the console and the other

serves as a point of contact with the switch. Step 17 illustrates:

17. "From the underside of the console, insert a short bolt through the hole numbered 64."

The fifth chunk, Steps 22-29, involves assembly of the lamp. The critical steps here include placing a bolt through an appropriate hole in the console, using this bolt to mount the lamp's socket to the console, inserting one end of a wire into the socket, and screwing the bulb into the socket. Step 23 is an illustration:

23. "Push a short bolt through the washer and hole in the bulb holder's bottom so that bolt head is inside the bulb holder."

The final chunk includes Steps 30-34. These steps require connecting the three major components together. Step 31 is illustrative:

31. "Using a wire with sleeves on both ends, push one of its sleeves onto the long bolt in contact with the battery's positive pole."

2.1.2 Hierarchical instructions

The two other columns in Figure 2 depict what we have called the Structural and Functional versions of the same instructions. Both of these versions differ from the Linear one only in that they contain additional explanatory information. Some of this additional material occurs prior to any steps (e.g., Statements

III-IX in the Structural version), while the rest is interspersed between chunks of steps (e.g., Statements X-XIX in the Structural version). Note that this additional material -- which we refer to as statements to distinguish it from steps -- occurs in virtually the identical positions for the Structural and Functional instructions.

Consider first the statements for the Structural instructions. Statements III and IV describe a general schema for assembly of a circuit:

III. "Assembling a circuit requires that you get the major components ready, then connect them."

IV. "It is often the case that the components themselves have to be assembled first."

Other statements may be viewed, roughly, as instantiations of this schema. Thus Statement V is an instantiation of III, and VI an instantiation of IV:

V. "This circuit has three major components: (1) battery, (2) switch, and (3) small lamp."

VI. "As a way of starting things off, we will first have you assemble the battery."

Similarly, other statements may be viewed as instantiations of instantiations of the top-level schema. Thus VII and VIII are, roughly, instantiations of VI.

VII. "In this case the major components of the battery consist of two dry cells."

VIII. "And the minor components of the battery consist of wire,

bolts, and nuts."

It should be noted, however, that not every structural-explanatory statement was transparently an instantiation of the general schema. Consider IX:

IX. "The first thing that you will do is to wire together two bolts that will be placed in contact with the dry cells."

This statement specifies what components are to be connected in assembling a major component, and hence is technically speaking an instantiation (of an instantiation of the general schema); still, IX seems less related to our general schema than do the other explanatory statements we have considered. A similar story holds for some of the remaining structural explanatory statements, X-XIX. Technically, they are all instantiations of our general assembly schema, but some are clear-cut instantiations while others seem less so.

The situation is similar for the Functional instructions (see the rightmost column of Figure 2). Statements III', IV', and V' give something of a general schema for current flow:

III'. "In a circuit, electric current flows from a 'source' to a 'consumer' (i.e., to something that requires current, like a lamp)."

IV'. "Current can flow only when the circuit's components are interconnected in a complete circle, each connection being made by a wire or other metal object that conducts electricity."

V'. "This circuit's major components are a battery, the source of the current; a lamp, the main consumer; and a switch, which in ON position forms a connection that

allows current to flow."

Again, succeeding statements were, technically speaking, instantiations of this general schema, though some were clearly so (see VIII') and others less so (see XII').

VIII'. "The first thing that you will do is to make the wire connection that will later be used to link the two dry cells."

XII'. "Next, you'll construct the on-off switch by connecting a metal spring to two bolts."

(The complete sets of Linear, Structural and Functional instructions appear in Appendix A.)

2.1.3 Propositional nature of the instructional steps

Variations in explanatory material can induce variations in how one perceives the steps to be organized. But in addition to the organization of steps, we need to give some consideration to the steps themselves. In these experiments, we manipulated only one aspect of step content, namely the number of propositions in a step.

Propositions were determined by a coding system similar to that used by Kintsch and his coworkers (e.g., Kintsch, 1974; Turner & Greene, 1977; Kintsch & van Dijk, 1978). In this system, each action-verb, adverb, or adjective in a sentence typically adds one proposition. We can illustrate our propositional analysis with some of the sample steps we presented earlier. Thus, Step 2 would be analyzed into three propositions:

- 2. "Now you are to wrap one end of the wire around one of the short bolts."
- 2a. WRAP (wire-end 1, bolt 1)
[This propositions is roughly translatable as
"Wrap a particular wire-end around a particular bolt"]
- 2b. SHORT (bolt 1)
[Roughly, "The particular bolt is short"]
- 2c. NOW (2a)
[Roughly, "Now is the time to do the wrapping"]

In this example, there is no separate proposition asserting that "The particular wire has an end," because such a proposition occurred in the previous step.

Step 17 offers an example of a four-proposition step:

- 17. "From the underside of the console, insert a short bolt through the hole numbered 64."
- 17a. INSERT (bolt 2, hole 1)
[Roughly, "Insert a particular bolt in a particular hole"]
- 17b. SHORT (bolt 2)
- 17c. NUMBER-OF (hole 1, 64)
[Roughly, "The number of the particular hole is 64"]
- 17d. LOC (17a, underside)
[Roughly, "The location of the insertion is the underside (of the console)"]

A five-proposition step is illustrated by Step 31:

- 31. "Using a wire with sleeves at both ends, put one of its sleeves onto the long bolt in contact with the battery's positive pole."
- 31a. USE (wire 2)
- 31b. HAS (wire 2, sleeve-sockets 2a & 2b)
[roughly, "The particular wire has two sleeve sockets."]

- 31c. PUT (sleeve-socket 2a, bolt 3)
- 31d. LOC (bolt 3, contact-positive-pole)
[roughly, "The location of the particular bolt is at a point of contact with the positive pole."]
- 31e. HAS (battery, positive pole)

Finally, a six-proposition step is illustrated by Step 23:

- 23. "Push a short bolt through the washer and hole in the bulb-holder's bottom so the bolt head is inside the bulb holder."
- 23a. PUSH (bolt 4, washer 2 - hole 2, ACHIEVE)
[roughly, "Push a particular bolt through a particular washer-and-hole so as to achieve a particular state of affairs."]
- 23b. ACHIEVE = LOC (head 4, inside-bulb holder 1)
[roughly, "The state of affairs that 23a wants to achieve is that the location of the head of the particular bolt be inside a particular bulb holder."]
- 23c. SHORT (bolt 4)
- 23d. HAS (bolt 4, head 4)
- 23e. HAS (bulb-holder, hole 1)
- 23f. LOC (hole 1, bottom-of bulb-holder 1)
[roughly, "The particular hole is in the bottom of the particular bulb holder."]

While the preceding examples are generally in line with how kintsch and his coworkers break sentences into propositions, one aspect of the above is unique. This is our use of an ACHIEVE proposition in Step 23. Such a proposition is intended to describe a state of affairs that some major action should bring about; we mention the ACHIEVE proposition as one argument in the proposition describing the major action (see 23a) and then use or define the ACHIEVE in a later proposition (23b).

2.2 Procedure

2.2.1 Overview

The experiment included five stages. Stages 1 and 2 were preliminary to the main instructions task and involved assessing certain of the subjects abilities that could be relevant to the instructions task. Stage 3 was the heart of the experiment -- reading and executing either the Linear, Structural, or Functional instructions-for assembling the circuit. The last two stages were intended to tap the knowledge that subjects had learned from the instructions. Stage 4 consisted of ten multiple choice questions, and Stage 5 required subjects to verbally recall the instructions.

2.2.2 Stage 1: Self ratings

Subjects filled out a three-item questionnaire that asked for their: (1) educational level; (2) self-rating of familiarity with electronics (rated on a 10-point scale where 1 indicated "no knowledge" and 10 indicated "a great deal of knowledge"); and (3) self-rating of manual dexterity (rated on a 10-point scale where 1 indicated "very poor" and 10 indicated "excellent"). Subjects filled out the three items at their own rate, and none took longer than a minute or two.

2.2.3 Stage 2: Reading span

Subjects were administered Daneman and Carpenter's (1980)

reading-span task, a measure of active memory that has been shown to correlate with some measures of reading comprehension. The reading-span task requires subjects to first read a sequence of sentences and then recall in order the last word of each sentence. We started subjects off with a sequence of just two sentences; if they could perform this task perfectly twice in a row, we increased the sequence length to 3; we reiterated this procedure until we hit a sequence length the a subject failed to be perfect on in either of two attempts. The subject's reading span was defined at the highest sequence length they were perfect on plus partial credit for any words they recalled correctly with the last sequence length. For example, a subject who had two perfect trials with a sequence length of 5, but only two words correct with a sequence length of 6, would get a score of 5.3.

After subjects had completed Stages 1 and 2 the experimenter inspected their results and assigned them to one of three groups (corresponding to Linear, Structural, or Functional instructions) so as to roughly equate the groups with respect to education level, familiarity with electronics, manual dexterity, and reading span.

2.2.4 Stage 3: Instructions task

We have already discussed in detail the three sets of instructions used in this task. What remains to be described is the procedure that subjects used to advance through the instructions, one statement or step at a time. This procedure is

depicted in Figure 3. To illustrate, consider the first time that a particular step, Step n, appeared on the display. Subjects read the step and pressed either a continue (C) or back-up (B) button. Depression of either button terminated a clock, and the time was taken as the first-reading-time for Step n (RT_n). If the subject pushed the continue button (the right branch of Figure 3), the following occurred: (1) Step n went off the screen and was replaced by a prompt that read "Back-up or Continue?"; (2) the subject turned to the right of the screen to the circuit-assembly task, and executed the step; and (3) the subject turned back to the screen, read the prompt and pushed either the continue or back-up buttons, where depression of either button stopped a clock and added the time to an execution-time file for Step n (ET_n). If the subject pushed the back-up button to Step n (the left branch of Figure 3), the following occurred: (1) Step n went off the screen and was replaced by Step n-1¹; (2) the subject re-read Step n-1 and pressed either the continue or back-up button, where depression of either button stopped a clock and added the time to a reading-time total for Step n-1 (RT_{n-1}). Other procedural possibilities should be evident from Figure 3.

Though the procedure allowed subjects to back up at any point, in fact there were relatively few backups. Likely this

¹ If an explanatory statement had intervened between Steps n and n-1, then it rather than Step n-1 would appear on the screen.



Figure 3. Procedure for instructions task.

occurred because the experimenter gave the subject assistance during execution that essentially prohibited the subjects from pursuing an incorrect sequence of actions. Specifically, the experimenter informed the subject if she made an execution error, told her the correct action to take in the event of such an error, and assisted her in those few cases where the subject seemed to lack the dexterity to complete an action.

To insure familiarity with the procedure, subjects first participated in a practice task that involved assembling a toy pump. Instructions for this practice task included a total of eleven steps and four statements.

2.2.5 Stage 4: Question-answering

. This stage consisted of a ten-item multiple-choice test. Seven of the questions asked about the consequences of a possible change in the circuit assembly. For example,

"Would the bulb light up if the switch had been connected to the negative pole and the light bulb to the positive pole, instead of the way you did it?"

- a Yes
- b No
- c Impossible to determine

The remaining three questions asked for the rationale behind particular steps. For example,

"What would happen if the nut on the bolt holding the switch in place was not tightened?"

- a Switch would be too loose to use properly
- b Could not put plastic sleeve on that bolt

c Switch would be loose, but
would still work

2.2.6 Stage 5: Recall

The circuit was completely disassembled (outside the view of the subjects). Then the disassembled circuit was shown to the subjects who were told to recall in writing all the instructions.

2.2.7 Summary

Table 1 summarizes the five stages of the experiment.

2.3 Subjects

The subjects were 36 females, either students at Leslie College in Cambridge, Massachusetts, or secretaries at BBN. The 36 subjects were divided equally among the three instructional groups -- Linear, Structural and Functional.

2.4 Results: Preliminary

Before moving on to our two main orders of business -- evaluating performance effects at the level of the organization of steps and at the level of the individual step -- we need to briefly consider the data from Stages 1, 2, and 4 of the experiment (see Table 2). With regards to the questionnaire results from Stage 1, we were successful in equating the instructional groups on the three variables of interest: education level, familiarity with electronics, and

Table 1

Stages of Experiment 1

1. Self ratings
2. Reading span
3. Instructions task
 - a. Practice - toy water pump
 - b. Test - electrical circuit
4. Multiple-choice questions
5. Verbal recall

Table 2

Results from Stages 1, 2, and 4 (Experiment 1)

	<u>Linear</u>	<u>Structural</u>	<u>Functional</u>
1. Self ratings			
Education level (years)	14.9	14.7	14.6
Familiarity (1-10 scale)	1.5	1.6	1.3
Dexterity (1-10 scale)	5.4	5.3	6.3
2. Reading span	5.8	5.8	6.0
4. Multiple-choice questions (average no. correct)	7.3	7.8	7.2

manual dexterity. The between group differences on these variables do not even approach significance ($F < 1$ for all three variables). It is also worth pointing out that, on the average, our subjects had close to minimal familiarity with electronics.

We were also successful in equating the Stage-2 reading spans across groups, as shown by the fourth row of data in Table 2. Again, the between-group differences do not even approach significance ($F < 1$). The final row of Table 2 gives the data for the multiple-choice questions. There are no significant group differences here either ($F < 1$). Subsequent inspection of these questions suggested that several of them were too easy to provide any discrimination between the three groups.

2.5 Results due to organization of steps

While the data we are about to present reflects effects due to the content of specific steps as well as to the organization of steps, only the latter is of concern now. Our discussion will be organized around three different tasks or dependent measures - reading times, execution times, and recall percentages.

2.5.1 Reading times

Figure 4 presents the average reading time per syllable for each step, separately for the Linear, Structural, and Functional groups. These times are for the first occurrence of a step (there were too few back-ups to analyze). Obviously there is a

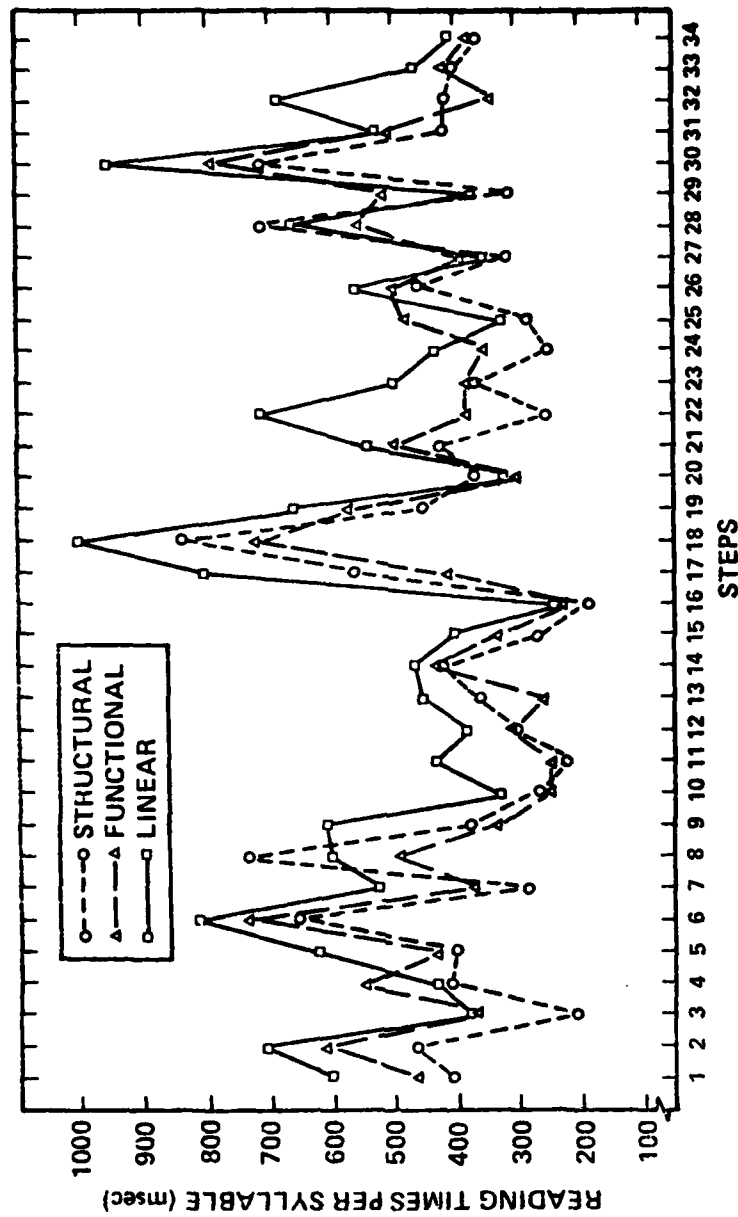


Figure 4. Reading times per syllable for each step (Experiment 1).

substantial effect due to the individual steps themselves, as the reading times fluctuate widely from step to step. But our concern now is with the organization of steps, and at this level the major finding is that reading times are faster with Structural or Functional instructions than with Linear ones. Indeed, the Structural group is faster than the Linear one at 31 of the 34 steps ($p < .001$), while the Functional group is faster than the Linear at 30 of the 34 steps ($p < .001$).

Since the graph is very dense when every step is plotted, we have chunked the steps in all subsequent graphs. In Figure 5 we have plotted reading times for nine chunks of steps, separately for the three instructional groups. (The chunks, which are labelled by the major component involved, are the ones we noted earlier when we illustrated the three types of instructions plus a few other distinctions: the chunk corresponding to Steps 1-7 has been split into two subchunks, and similar divisions have been made for the chunks corresponding to Steps 14-21 and 22-29.) Reading times are clearly faster for Structural and Functional instructions than for Linear ones. The superiority for the Structural group shows up at all 9 chunks, while that for the Functional group manifests itself at 8 of 9 chunks. There seems to be little difference between the Structural and Functional groups. It is also worth mentioning that the reading-time functions for the three instructional groups are relatively similar as the three curves tend to rise and fall together.

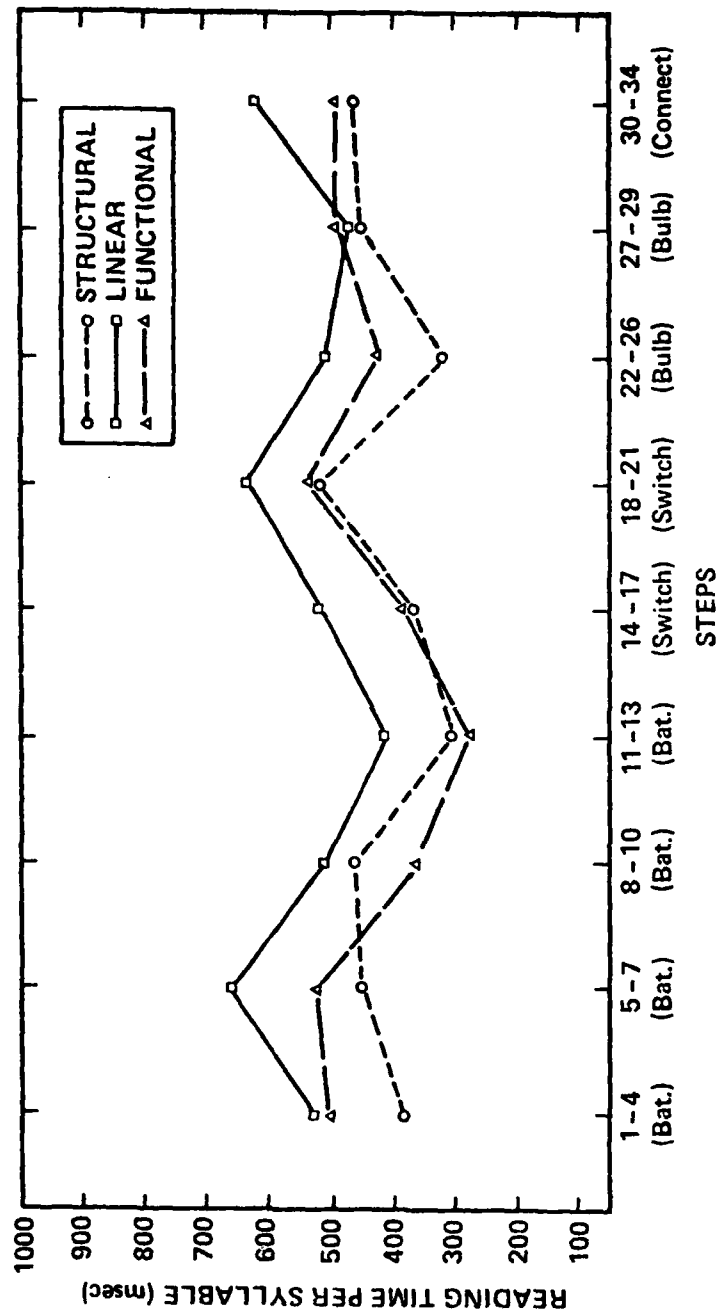


Figure 5. Reading times per syllable for chunks of steps (Experiment 1).

The above conclusions are supported by statistical analysis of the reading times. An analysis of variance showed significant main effects of both steps and instructional group (for steps, $F(8,240)=8.07$, $p<.001$; for groups, $F(2,30)=2.84$, $p=.06$), but no interaction between the two factors ($F=1.0$). Furthermore, reading times per step were correlated between instruction groups: the Spearman product-moment correlation between the Linear and Structural groups over steps was .78, that between the Linear and Functional groups was .72, and that between the Structural and Functional group was .77 ($p<.01$ in all three cases). The fact that the correlations between each Hierarchical group and the Linear group was substantially less than 1 does leave some room for explanatory material to have differential effects on the various steps; we shall consider such differential effects later when we take up the determinants of the Hierarchical advantage.

2.5.2 Execution times and errors

Times to execute the steps are presented in Figure 6. Now the times are measured in seconds rather than milliseconds, but again they are plotted as a function of chunks of steps with separate functions for the three instructional groups. Once more there is a substantial effect due to the individual steps, but as before our prime concern is at the level of organization of steps. And at this level there seems to be little difference between the three instructional groups except for the Functional

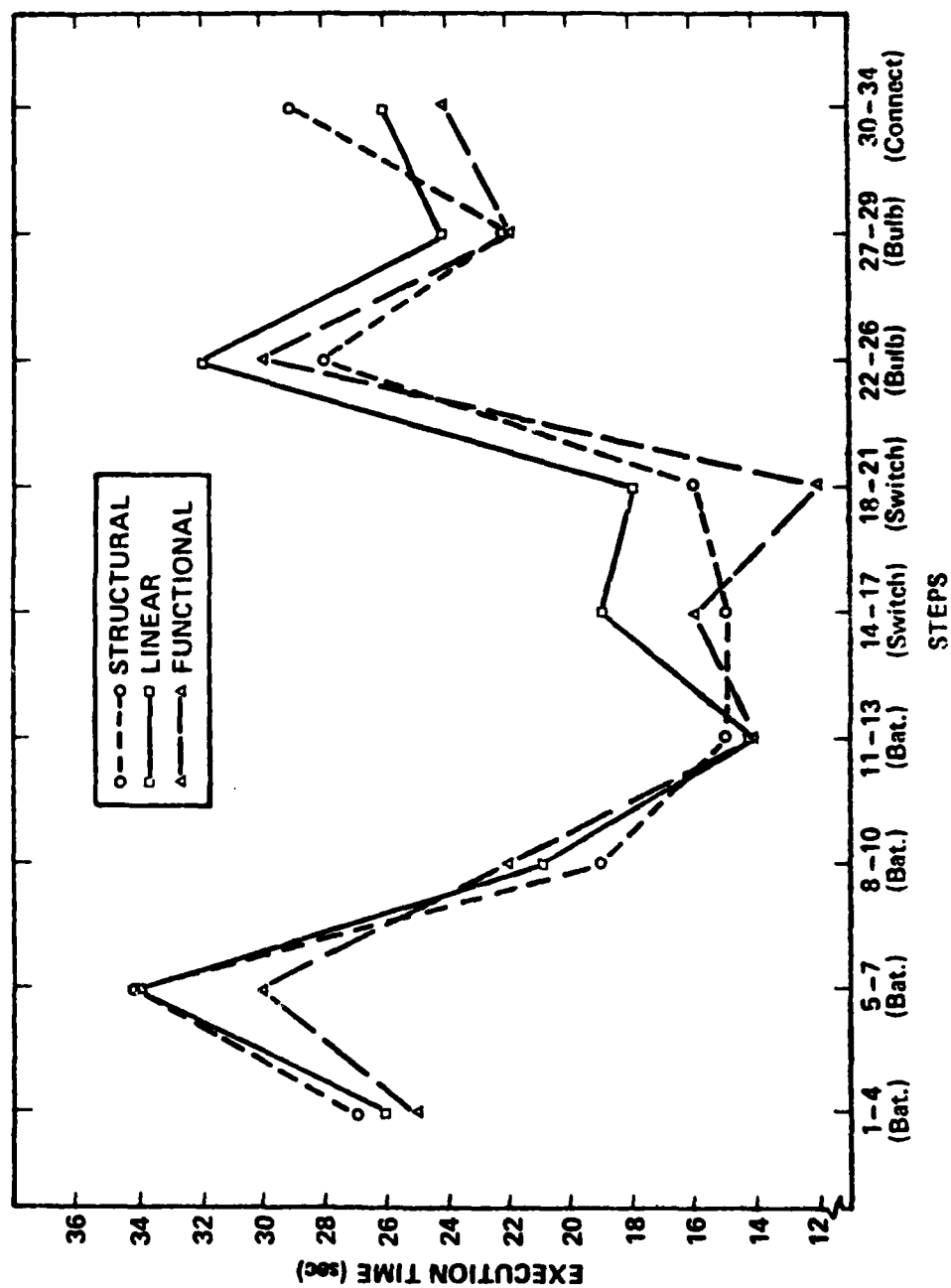


Figure 6. Execution times for chunks of steps (Experiment 1).

group being a bit faster than the other two groups. The apparent advantage of the Functional instructions did not prove statistically reliable. In an analysis of variance of the execution times, both the instructions effect and its interaction with steps fell far short of significance ($F < 1$ in both cases), and a post-hoc test of the Functional advantage also failed to reach significance ($F < 1$). The effect due to steps, however, was significant ($F(8,240) = 22.78$, $p < .001$).

One of the most striking aspects about the execution times in Figure 6 is how similar the functions are for the three instructional groups. This similarity is borne out by correlational analyses. The correlation between each pair of instructional groups over steps was extremely high; for the Linear and Structural groups, $r = .94$; for the Linear and Functional groups, $r = .94$; and for the Structural and Functional groups, $r = .93$ ($p < .01$ for all three cases).

While the execution times failed to reveal differences due to instructional group, the frequency of execution errors proved more sensitive. The average number of execution errors per subject was 5.6 in the Linear group, which was marginally greater than the average number of errors in both the Structural group 3.3, ($t(22) = 2.05$, $p < .05$), and in the Functional group, 3.9, ($t(22) = 1.45$, $p = .08$), while the two hierarchical groups did not differ from one another ($t(22) < 1$).² The fact that we obtained

² These t tests are one-tailed.

these accuracy advantages for Hierarchical instructions is quite striking given that we reduced the opportunity for errors by giving the subjects' assistance during execution.

2.5.3 Recall percentages

In what follows, we consider the recall of only steps. Subjects in the Structural and Functional groups recalled few explanatory statements, and a couple of subjects volunteered that they treated the mandate to "recall all instructions" as equivalent to "recall all steps."

To score the recall data, first we analyzed each step into its underlying propositions using the system discussed earlier. Then we scored the subjects' written recall in terms of these propositions. Figure 7 plots the percentage of propositions recalled from each chunk of steps, separately for the three instructional groups. As usual, there is an effect due to the individual step. With regard to the organization of steps, however, the Functional group seems somewhat better than the Linear one, while the Structural group seems superior to the other two. These differences are clearer in Figure 8. Here the dependent measure is a difference in recall percentages, either a difference between the Structural and Linear groups or a difference between the Functional and Linear groups. To the extent these differences are positive, recall is better under Structural or Functional instructions. Recall scores were in fact higher in the Structural than the Linear group in 8 out of 9

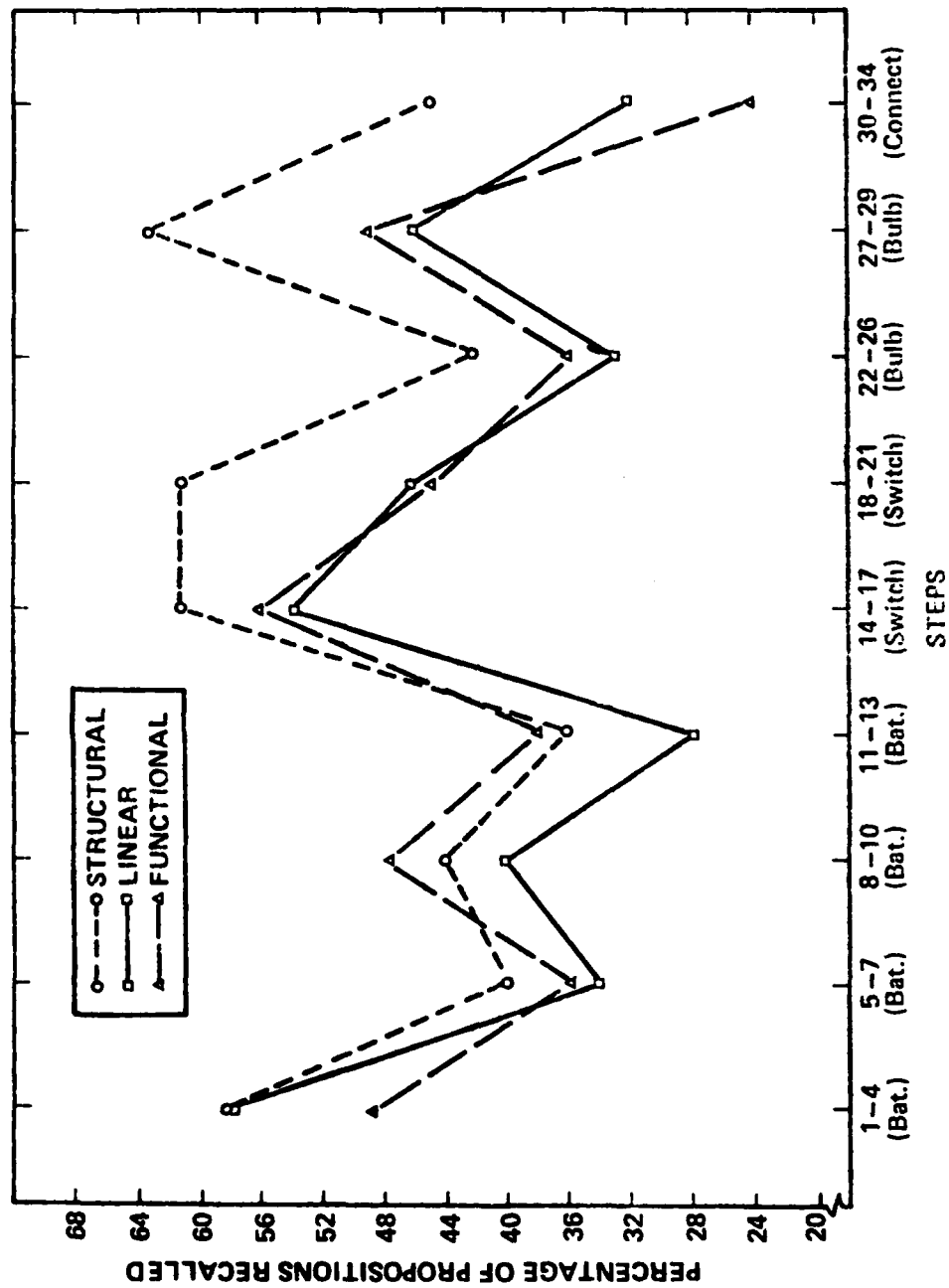


Figure 7. Percentage of propositions recalled for chunks of steps (Experiment 1).

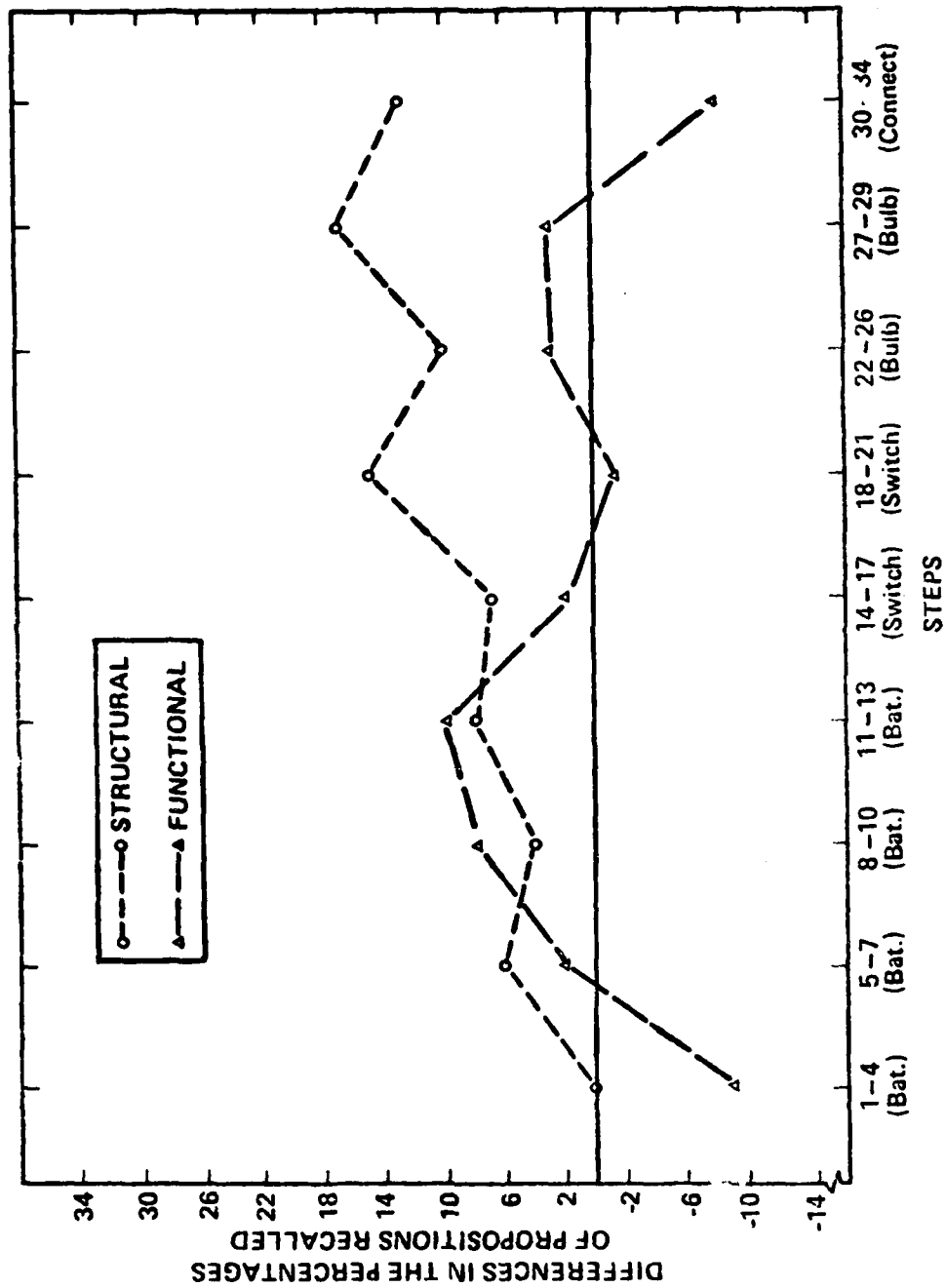


Figure 8. Recall advantages for Hierarchical groups, separately for Structural and Functional groups (Experiment 1).

possible comparisons, whereas the advantage of the Functional over the Linear groups was less consistent. Once again, the other important aspect about the data is that the functions for all three instructional groups are similar (see Figure 7).

Again, there is statistical support for our conclusions. An analysis of variance turned up significant, or borderline-significant, main effects of both instructions ($F(2,30)=2.64$, $p<.10$, and steps $F(8,240)=23.98$, $p<.001$), but a nonsignificant interaction between them ($F(16,240)=1.27$, $p>.10$). And we obtained high correlations, across steps, between the Linear and Structural groups, $r=.86$ ($p<.01$), between the Linear and Functional groups, $r=.80$ ($p<.01$), and between the Structural and Functional groups, $r=.67$ ($p<.05$).

2.6 Determinants of the Hierarchical advantage

We now want to consider specific mechanisms that may have been responsible for the better performance with Hierarchical than Linear instructions. Before doing so, we briefly summarize the major results.

2.6.1 Summary of major results

(1) Less time is needed to read a step with Structural or Functional instructions than with Linear ones. This suggests that explanatory material (and/or hierarchical structure) makes steps easier to understand;

(2) Somewhat fewer errors are committed when executing a step with Structural or Functional instructions than with Linear ones. This also suggests that explanatory material (and/or hierarchical structure) makes steps easier to understand;

and

(3) More propositions from each step are recalled with Hierarchical instructions, particularly Structural ones, than with Linear instructions. This finding is compatible with explanatory material facilitating understanding (assuming that memory improvement is a consequence of increased understanding); alternatively, the present finding may indicate a direct effect of explanatory material on memory.

While the Structural and Functional instructions differ somewhat in their performance effects (i.e., Structural instructions led to better recall), by and large they produced comparable results in this experiment. This suggests that there are some common mechanisms underlying the beneficial effects of the two kinds of Hierarchical instructions. In what follows, we will focus on these communalities. (Later, when we turn to Experiment 2, we will consider the differences between Structural and Functional instructions.)

2.6.2 Prior activation

In the Introduction we suggested that Structural or Functional instructions might facilitate understanding by

providing an explanatory schema for the steps. Thus a concept used in an explanatory statement might be instantiated by something mentioned in a step. We can illustrate with the Structural instructions. Statement IX preceded Step 1.

IX. "The first thing that you will do is wire together two bolts that will be placed in contact with the dry cells."

(1) "Select the short red wire that has been stripped at both ends."

Clearly the specific wire referred to in Step 1 can be viewed as an instantiation of the general wire referred to (or presupposed) in IX. Thus a step instantiating the schema typically contains concepts connected to those in the schema; and this suggests that such steps are preactivated. Perhaps, then, the beneficial effect of explanatory material on the understanding of an executable step is due to such of prior activation.³

To evaluate this hypothesis, first we determined whether or not each step in the Hierarchical instructions had received any prior activation from an explanatory statement. This determination had to be done separately for the Structural and Functional instructions since the steps receiving prior activation differed somewhat between the two sets of instructions. To the extent that the Hierarchical advantage in

³ This is similar though not identical to Kintsch's notion of argument repetition (e.g., Kintsch, 1974; Kintsch & van Dijk, 1978).

reading is due to prior activation, the advantage should be confined to, or at least be greater for, those steps receiving prior activation. The relevant data are in Table 3. There we have plotted the reading time advantages for the Structural and Functional instructions -- the reading time for a step in the Linear group minus the time for the same step in the Structural or Functional group, averaged over all relevant steps. These advantages are given separately for steps that have received prior activation and those that have not (as well as for all steps). As expected, the reading-time advantage for both types of Hierarchical instructions is greater for steps that have received prior activation than for steps that have not; for the Structural group, $t(32)=2.52$, $p<.01$; for the Functional group, $t(32)=2.48$, $p<.01$. Thus part of the beneficial effect of explanatory material on reading seems to be due to its activation of concepts that will soon be needed in understanding executable steps.

2.6.3 Chunking

The preceding analysis focused on the content of the explanatory material. Another aspect of the explanatory material, however, was its hierarchical nature, which led to a chunking of the steps. To appreciate this, consider again Figure 2 (repeated here for convenience); with both kinds of explanatory material, Steps 1-7 are in one chunk, 8-10 in another, 11-13 in a third chunk, and so on. Such chunking might have been

Table 3

Reading-Time Advantages and Prior Activation (Experiment 1)

	<u>Linear-Structural</u>		<u>Linear-Functional</u>	
Activated	163 msec	(N=22)	146 msec	(N=18)
Not Activated	66 msec	(N=12)	44 msec	(N=16)
All Steps	128 msec	(N=34)	98 msec	(N=34)

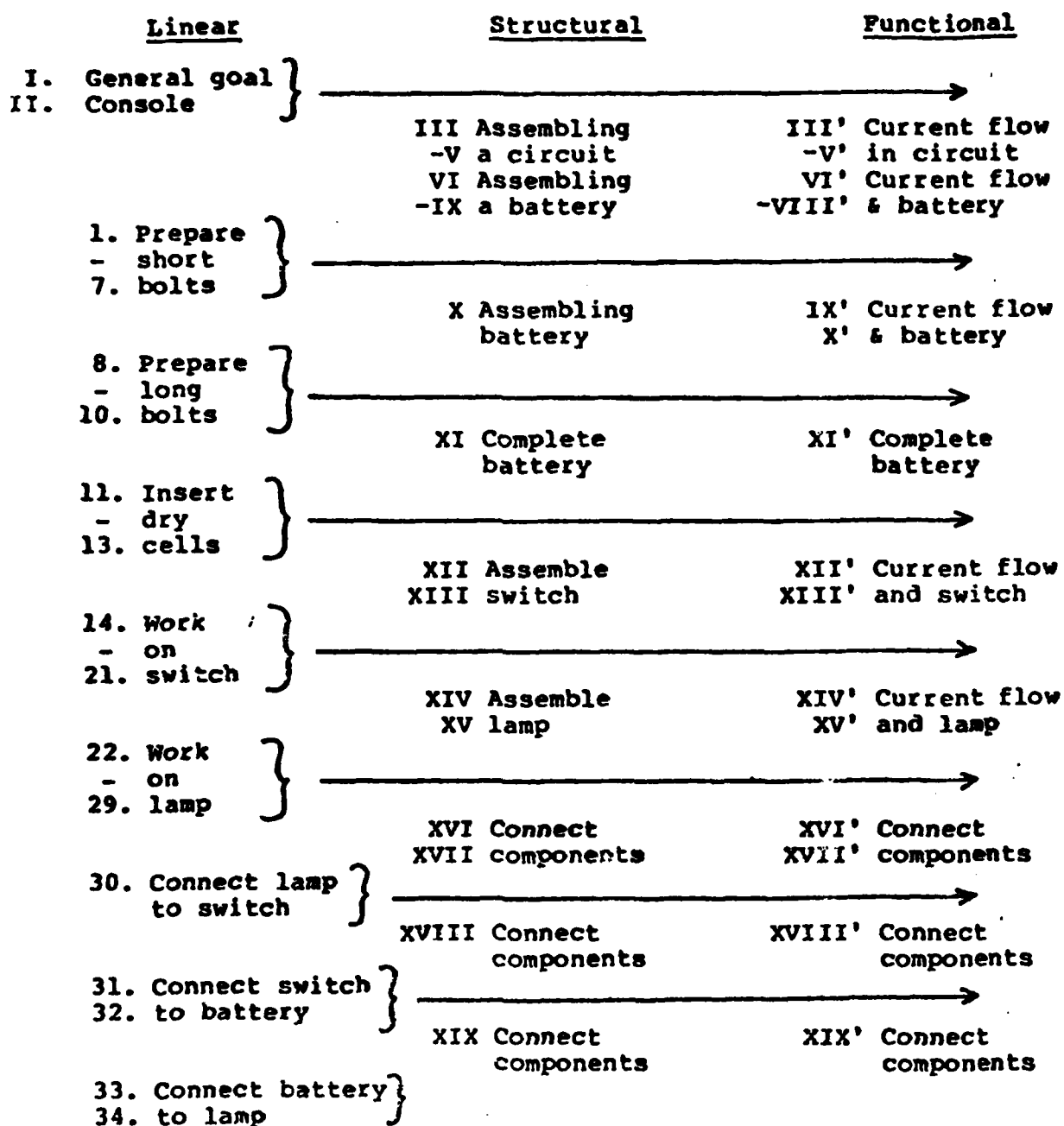


Figure 2. Three types of instructions for assembling an electrical circuit.

responsible for the better recall of steps in the Hierarchical groups than the Linear one.

A standard way of evaluating chunking in verbal recall is to consider $P(I_j/I_i)$, the conditional probability that Item j is recalled given that Item i has been recalled; since chunks are presumably accessed as units, $P(I_j/I_i)$ should be higher when i and j are in the same chunk than when they are in different ones. Applying this logic to our experiment, we identify I_i and I_j with successive steps, and predict $P(I_j/I_i)$ to be higher for within-chunk steps than for between-chunk steps. Moreover, this prediction should hold only for the Structural and Functional groups, not for the Linear one. The results of this test are presented in Table 4. For all three instructional groups, $P(I_j/I_i)$ is higher when I_i and I_j are from the same chunk than when they are from different ones. However, the difference between same and different chunks is greater for the Structural and Functional groups than the Linear one.

2.6.4 Summary

We have some evidence that the Hierarchical advantage in reading a step is partly due to prior activation of the step's concepts, and that the Hierarchical advantage in recall is partly due to chunking of steps. This hardly exhausts the mechanisms involved in the Hierarchical advantage. For one thing, there seems to be far more to explanation- or schema-based understanding than just prior activation of concepts, but we have

Table 4

Probability Step j is Recalled
Conditional on Step i Being Recalled
(Experiment 1)

	Type of Instruction		
	Linear	Structural	Functional
Same chunk	.50	.80	.68
Different chunk	.25	.42	.23

not yet determined how best to experimentally test these other mechanisms. For another, our chunking explanation does not offer any account of why recall was better in the Structural than the Functional group (chunking was equivalent in these two groups). Still, the analyses just presented at least provide a beginning account of the Hierarchical advantage in terms of familiar cognitive mechanisms.

2.7 Results due to specific steps

We now want to consider some results that reflect the contents of individual steps. Again, our discussion will be organized around three dependent measures: reading times, execution times, and percentage of propositions recalled.

2.7.1 Reading times

Let us return to Figure 4 (repeated here with some additional information at the bottom) where reading times are plotted for each step, separately for three instructional groups. Rather than focusing on the effects of instructions, now we want to understand effects due to the steps themselves; i.e., what makes some steps more difficult than others? We have isolated two determinants of step difficulty: the number of propositions in a step (which we explicitly varied) and the type of a step (which we will soon define). We can get a glimpse of the effects of these two factors from the present figure, since the bottom rows of Figure 4 give the number of propositions and an

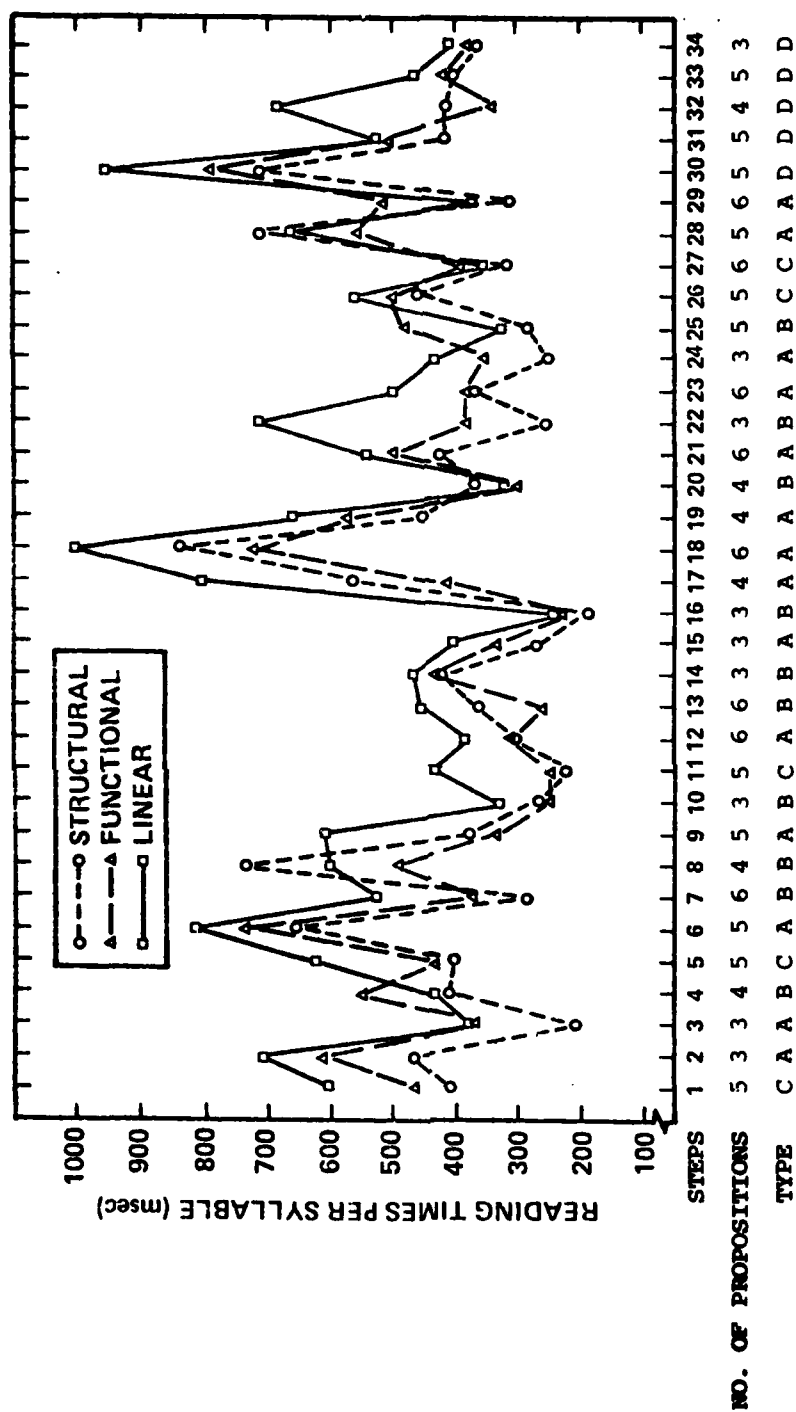


Figure 4. Reading times per syllable for each step. The number of propositions and the post-hoc typology for each step are included (Experiment 1).

indication of type for each step. Thus, note that the two steps with the longest reading times -- Steps 18 and 30 -- have six and five propositions, respectively, while the two steps with the shortest reading times -- Steps 3 and 16 -- each have only three propositions. Similarly, note that many of the longer reading times are for steps that we have labelled as Type A -- Steps 2, 6, 17, 18, 19, and 28.

Figure 9 offers a clearer look at the propositional factor. Reading times are plotted as a function of the number of propositions, separately for the three instructional groups. The pattern of results is similar for all three groups. As the number of propositions increased from 3 to 4 to 5, so did reading times. This much is in line with the work of Kintsch (e.g., 1974) and others on the effects of number of propositions on reading stories. But when the number of propositions was further increased to 6, reading times decreased. One possible reason for this unexpected decrease is that there are different kinds of propositions expressed in the steps, and the mixture of these kinds was quite different in the 6-proposition steps than in the other steps. For example, the 6-proposition steps were more likely than the other steps to contain ACHIEVE propositions, which are propositions that describe how an action is to be executed. Perhaps general information about an action and specific information about how it is to be executed are psychologically "glued" together, and what we are calling 6-proposition steps really contain fewer atomic ideas than that.

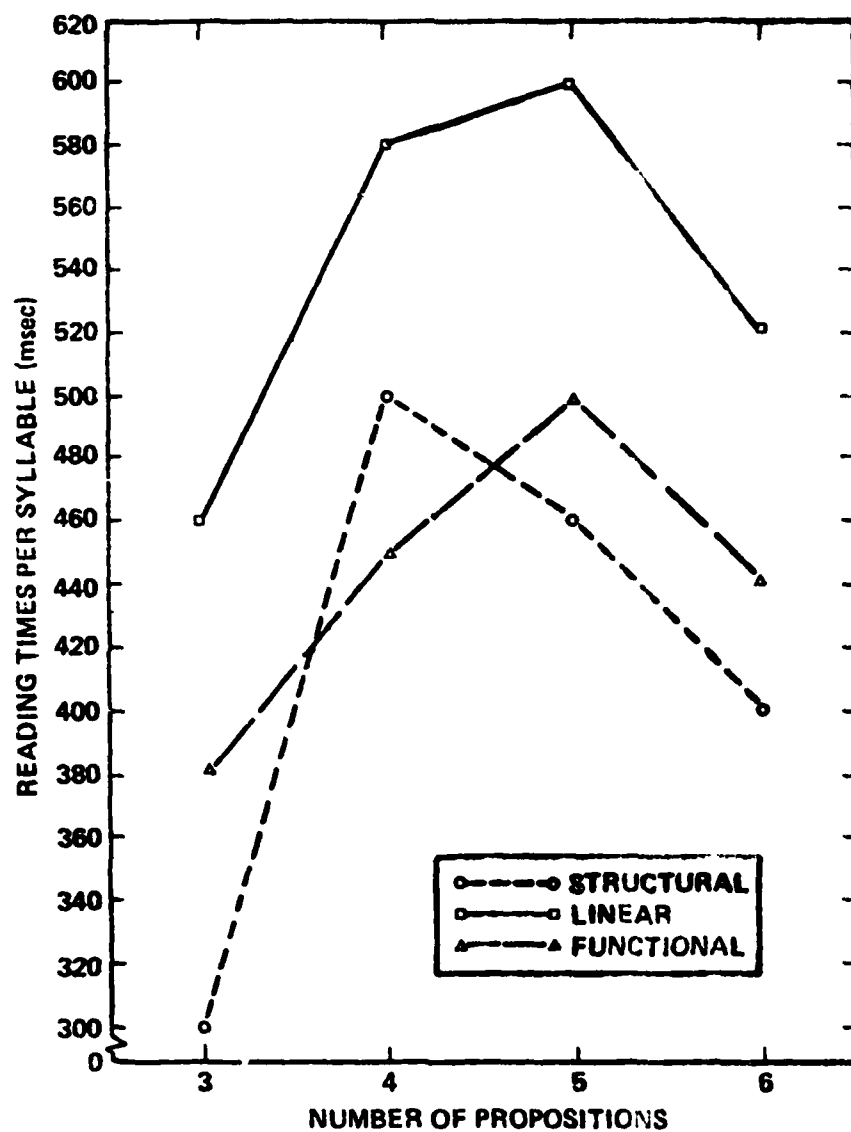


Figure 9. Reading times per syllable as a function of the number of propositions in a step (Experiment 1).

In any event, the overall effect of number of propositions is clearly significant ($F(3,90)=7.96$, $p<.001$).⁴

Our second factor, step type, is defined in Table 5. Four types of steps are given, along with the distribution of these types vis a vis the number of propositions. The first three step types involve assembling the major components of the circuit, while the fourth type involves connecting the major components once they are assembled. The first three types can themselves be distinguished as follows: Type A involves a relatively major action, like hooking a wire to a bolt or inserting a bolt in a groove; Type B involves a relatively minor fastening action, and always includes nuts and washers; and Type C always involves a locating action.

The effects of step type on reading times is portrayed in Figure 10. Again the pattern is similar for all three instructional groups. Type A and D steps -- those involving a relatively major assembly action or a connection of major components -- take longer to read than Type B and C steps -- those involving a fastening or a locating action ($F(1,30)=32.81$,

4

There is also a significant effect of instructions, which is hardly surprising given that this factor produced a significant effect in prior analyses. Also, there is no interaction between instructions and the number of propositions. In many of the following analyses in this section, these same two results occurred -- a main effect of instructions but no interaction; to avoid repetition, we omit further mention of them.

Table 5
A Typology of Steps

Type of Step	Number of Such Steps
A. Major Action	14
B. Minor Action (nuts, washers)	10
C. Locate	5
D. Connect components	5

Distribution of Step Types vis a vis Number of Propositions

Number of Propositions:		3	4	5	6
Type:	A	4	2	3	5
	B	4	3	1	2
	C	-	-	4	1
	D	1	1	3	-

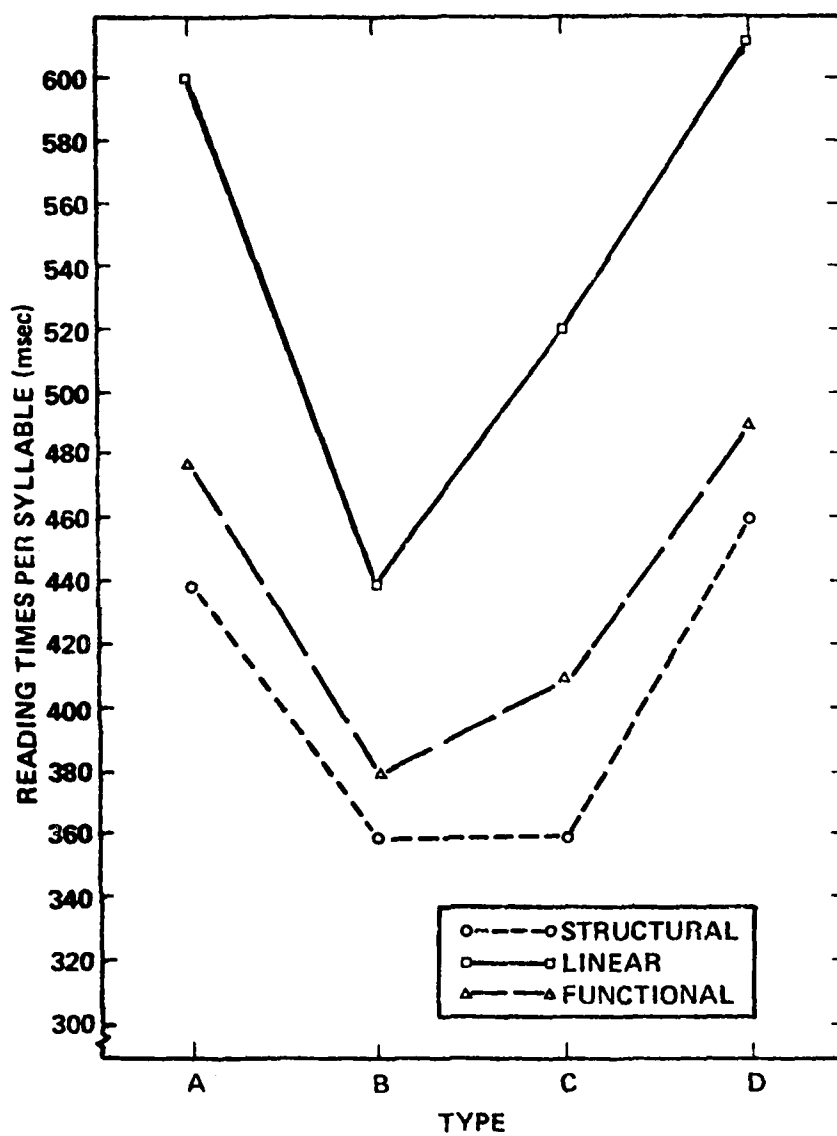


Figure 10. Reading times per syllable for each step type (Experiment 1).

⁵
 $p < .001$). We suspect that what lies behind this effect is that A and D steps are more important than B and C steps. If all B and C steps were deleted from the instructions, one could still assemble the circuit; in contrast, if the A and D steps were deleted, not only would assembly be impossible it would not even be clear what the instructions were about. So the data in Figure 10 may show for instructional texts what Cirilo and Foss (1980) have previously demonstrated for fictional ones: reading-time per line increases with the importance of that line to the overall text.

2.7.2 Execution times

In Figure 11 we have plotted execution times as a function of number of propositions. Again the pattern of results is the same for all three instructional groups: time increased as the number of propositions increased from 3 to 4 to 5, but then decreased as the number of propositions increased to 6. (For the overall effect of number of propositions, $F(3,90) = 5.45$, $p < .01$.) The fact that we obtained the same unexpected decrease for 6-proposition steps for execution and reading suggests that the same processes may be involved in both cases. Thus, our particular six-proposition steps, for whatever the reason, may

⁵
This F test is for the contrast between A and D steps on the one hand versus B and C steps on the other; only by grouping step-types in this way do we achieve some balance of step type over step number.

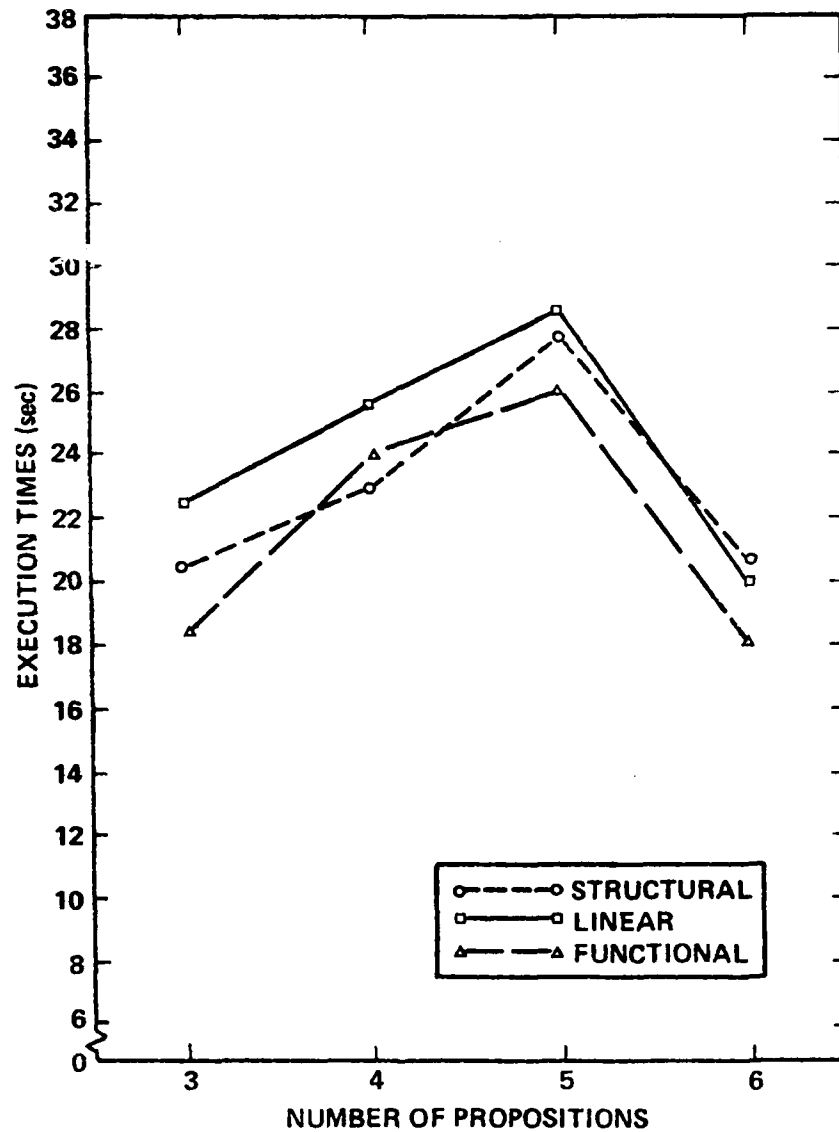


Figure 11. Execution times as a function of the number of propositions in a step (Experiment 1).

have required a relatively small load in active memory; the fewer the contents in active memory, the more readily they can be interconnected and consequently the faster the reading time; and the fewer the contents in active memory, the more readily the procedures they denote can be executed.

Figure 12 presents execution times as a function of step type. While the pattern of results is again the same for the three instructional groups, the nature of this pattern is different from what we observed with the reading times. B and D steps now take the longest, while C steps are clearly the fastest (for the contrast between A and D steps versus B and C steps, $F < 1$). What these data seem to reflect is that execution time is sensitive not to the importance of the step (vis a vis constructing a representation), but rather to something like the manual requirements of the step. Thus, fastening operations, though minor in importance, are relatively time consuming and often require a bit of manual dexterity, which is why B steps take so long; and locating actions require no manual operations, which is why C steps are executed faster than the other types. So the somewhat different demands of understanding and executing account for the differential effects of step type on reading and execution times.

2.7.3 Percentage recall

In Figure 13 we have plotted the percentage of propositions recalled from a chunk of steps as a function of the average

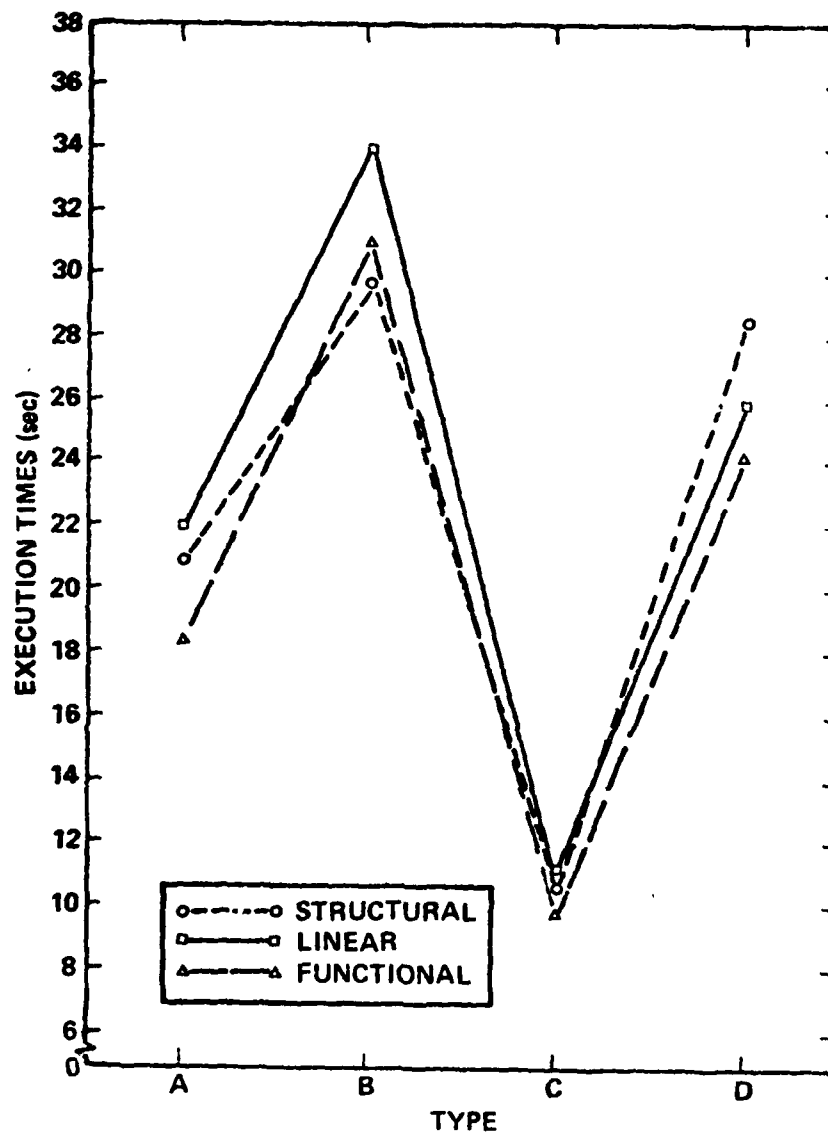


Figure 12. Execution times for each step type (Experiment 1).

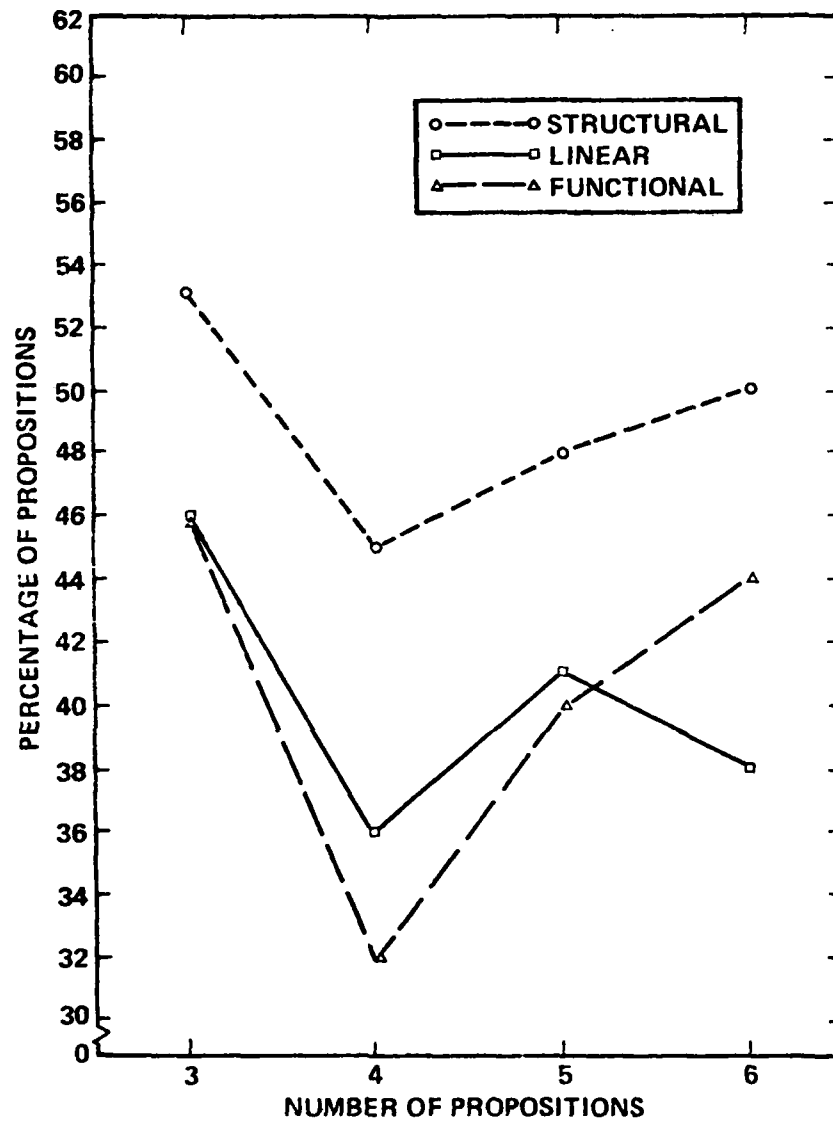


Figure 13. Percentage of propositions recalled as a function of the number of propositions in a step (Experiment 1).

number of propositions in that chunk. The initial drop in recall (from three to four propositions) is consistent with a well-known result in memory for word lists, the list-length effect, which means that the percentage of items recalled from a list declines with the number of items in the list (Crowder, 1976). In the present case, the number of propositions plays the role of the number of list items, and we therefore expect a consistent decline in recall with the number of propositions. That we get the decline only when going from three to four propositions may indicate that semantically integrated propositions do not function like unrelated list items. In any event, there was a significant effect of number of propositions ($F(3,90)=27.89$, $p<.001$).

Figure 14 presents percentage recall as a function of step type, and as usual the pattern of results is roughly similar for the three instruction groups. Performance is best on A steps, substantially poorer on B and C steps, and generally worst on D steps (for the contrast between A and D steps versus B and C steps, $F(1,30)=83.35$, $p<.001$). The fact that recall is better on A than on B or C steps fits with the reading-time results, where the more important A steps were read longer than the relatively minor B and C steps. Thus the better recall for the A steps may reflect either increased study time or the direct effect of importance on retrieval. What does not fit with the reading-time results is that D steps, which had relatively long reading times, were so poorly recalled. We suspect that the poor recall here is

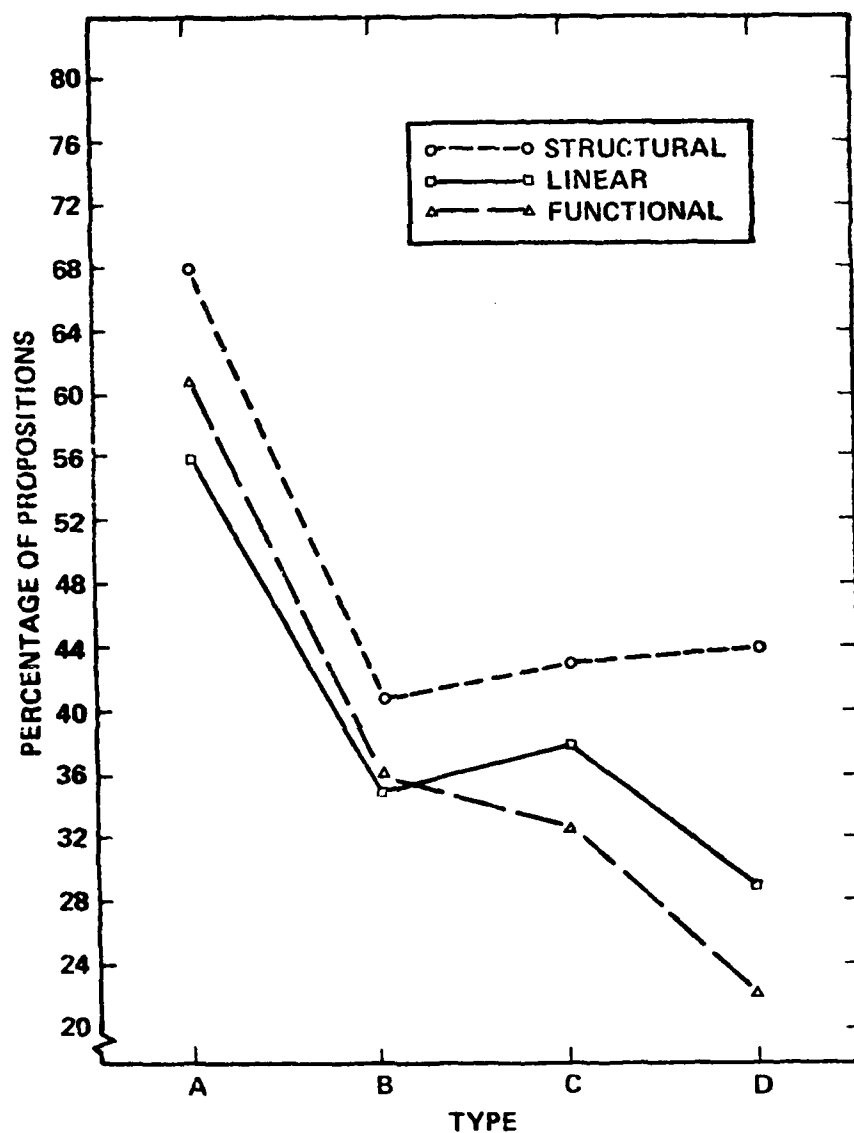


Figure 14. Percentage of propositions recalled for each step type (Experiment 1).

due to the extensive similarity among the D steps; all of them involved using a wire to connect two major components.

2.7.4 Summary

Number of propositions and type of step presumably reflect two different aspects of step difficulty, with the former factor indexing the amount that must be maintained in active memory, and the latter factor reflecting something about the relation between the propositions in one step and those in another. Both factors influenced all dependent measures of interest (reading time, execution time, and percentage recall). Indeed, these two factors may account for much of the variation due to steps that we have observed. While the number of propositions had the same kind of effect on all dependent measures -- performance generally declined as the number of propositions increased (at least up to five) -- step type had somewhat different effects on reading time, execution time, and percentage recall -- e.g., A and D steps were alike in reading times but different in recall. These differential effects of step type may be sufficient to account for the differences we observed earlier in the shapes of the functions relating step numbers to the various dependent measures.

One final comment about step type. If this factor really reflects importance of the step then it may result in differences in how the various steps are represented. Specifically, the representations of the less important B and C steps (fastening

and locating actions) may in some sense be dominated by the representations of the more important A and D steps (major assembly and connecting actions). For example, the representation of a step that involves locating a particular wire (a C step) may be at a lower level than the representation of a step that uses that wire (say, an A step). In essence, steps would be represented in a two-level hierarchy, with the more important A and D steps at the top level, and the less important B and C steps at the lower level. Note that this hierarchical structuring is orthogonal to that caused by Hierarchical instructions, for in the latter case all executable steps are at the same level (the bottom one).

3. EXPERIMENT 2

3.1 Rationale

This experiment was motivated by three concerns. First, we thought it important to try to replicate our major findings about a Hierarchical advantage in understanding instructions, particularly the widespread effect we obtained on reading times. Second, while our verbal recall task (Stage 5), had been a sensitive indicator of hierarchical organization, it is not a very ecologically-valid memory test for the instructional domain. A better choice along these lines would be a reconstruction task where subjects have to reassemble the circuit from memory. Third, we wanted to alter our multiple-choice test (Stage 4) so as to make it more sensitive to possible instructional group differences. This is particularly important because the knowledge tapped by these questions (e.g., the consequences of changing the circuit) is the kind needed in troubleshooting, and there are good a priori reasons to believe that Functional instructions should be more useful than Structural ones in troubleshooting. Trouble-shooting, after all, requires that one go from a functional failure to a structural cause, and only our Functional instructions provided information about function-structure mappings. Thus, with a more sensitive multiple-choice test, we would expect to obtain performance differences between Structural and Functional instructions.

3.2 The instructions

The same three sets of instructions were used with minor modifications of a few of the steps and explanatory statements.

3.3 Procedure

3.3.1 Overview

This experiment included only four stages, as we omitted the reading-span task of our earlier study.

3.3.2 Stage 1: Self-ratings

This stage was the same as in the previous study; i.e., self-ratings of educational level, familiarity with electronics, and manual dexterity. Again, the results were used as a basis for assigning subjects to the three instructional groups.

3.3.3 Stage 2: Instructions task

This stage was the same as in the previous study; i.e., a practice assembly task with a toy pump, followed by assembling the circuit one step at a time.

3.3.4 Stage 3: Question-answering

Our new question-answering task contained seven questions (none were multiple choice). The intent of the first four questions was to assess the subjects' conceptual understanding or underlying model of how circuits work. Questions 1 and 4, probably the most demanding, are given below:

(1) "In the space below draw a diagram of a simple circuit like the one you have just assembled. Use the appropriate symbols [presented in a separate table] to represent parts of the circuit. Show how these parts should be connected."

(4) "Using what you have learned in assembling our circuit, draw a diagram to show in detail the arrangement of the battery, bulb and switch in a flashlight."

Questions 5-7 explicitly required the subjects to troubleshoot a faulty circuit. For each of these questions, subjects were presented an incorrectly assembled circuit, told the problem with it (either the bulb wouldn't light or it wouldn't turn off), and asked to determine the cause of the problem. The cause involved either faulty connections between the major components or a misalignment of the dry cells.

3.3.5 Stage 4: Reconstruction

The circuit was completely disassembled (outside the subject's view). Then the subjects tried to reassemble it from memory.

3.4 Subjects

The subjects were 30 females from the same population as that of the previous experiment. They were divided equally among the three instructional groups.

3.5 Results: Preliminaries

The data from Stage 1 are presented in Table 6. Again, we were successful in equating the three instructional groups on education level, familiarity with electronics, and manual dexterity, as the between-group differences in Table 6 do not approach significance ($F < 1$ for all three variables).

3.6 Results due to organization of steps

3.6.1 Reading times

Figure 15 presents reading times for the various chunks of steps, separately for the three instructional groups. Reading times are faster for the Structural and Functional instructions than for the Linear ones, and there seems to be little difference between the two Hierarchical groups. An analysis of variance showed significant main effects of both steps and instructional group ($F(8,216)=13.01$, $p<.001$ and $F(2,27)=8.62$, $p=.001$), with a significant but rather trivial interaction between them ($F(16,216)=1.72$, $p<.05$). These results offer a convincing replication of the comparable findings in Experiment 1. Perhaps even more impressively, the shapes of the reading-time functions in Figure 15 are virtually identical to their mates in Experiment 1 (compare Figure 15 to Figure 6).

Table 6
Results from Stage 1 (Experiment 2)

	Type of Instructions		
	<u>Linear</u>	<u>Structural</u>	<u>Functional</u>
Self ratings			
Education level (years)	13.8	13.9	14.5
Familiarity (1-10 scale)	1.4	1.8	1.9
Dexterity (1-10 scale)	5.6	5.5	6.4

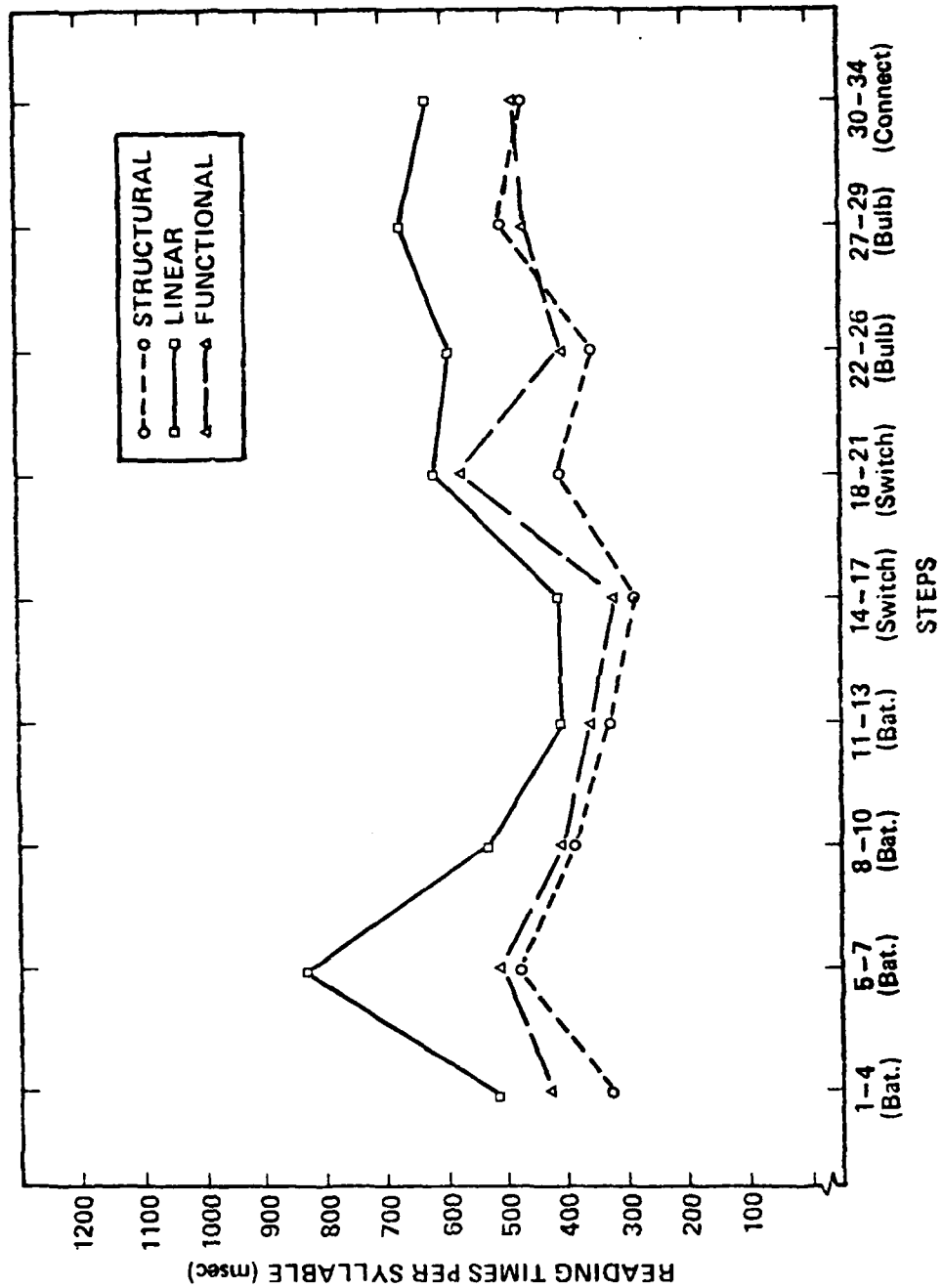


Figure 15. Reading times per syllable for chunks of steps (Experiment 2).

3.6.2 Execution times and errors

Execution times are presented in Figure 16 as a function of steps, separately for the three instructional groups. Again, the results offer a striking replication of the previous study. While execution times fluctuated widely with steps, there was no consistent effect of instructional group (for the steps factor, $F(8,216)=9.40$, $p<.001$; for the instructions factor, $F(2,27)<1$; for the interaction, $F(2,216)<1$). Also, the shapes of the present execution-time functions are virtually identical to those of the comparable functions in the previous study (compare Figure 16 to Figure 7).

As in the previous study, the average number of execution errors per subject was higher in the Linear group, 5.6, than in the Structural group, 5.5, or the Functional group, 4.1. However, there were no significant differences among these means ($p>.10$ in all cases).

3.6.3 Question-answering

The results for our revised question-answering task are presented in Table 7. As expected, the Functional group did best, 3.5 correct, and the Linear group poorest, 2.6 correct. Though in the expected direction, the differences between the groups did not reach an acceptable level of significance -- for the Functional vs. Linear contrast, $t(18)=1.13$, $p>.05$. However, this lack of statistical support seemed due to one aberrant

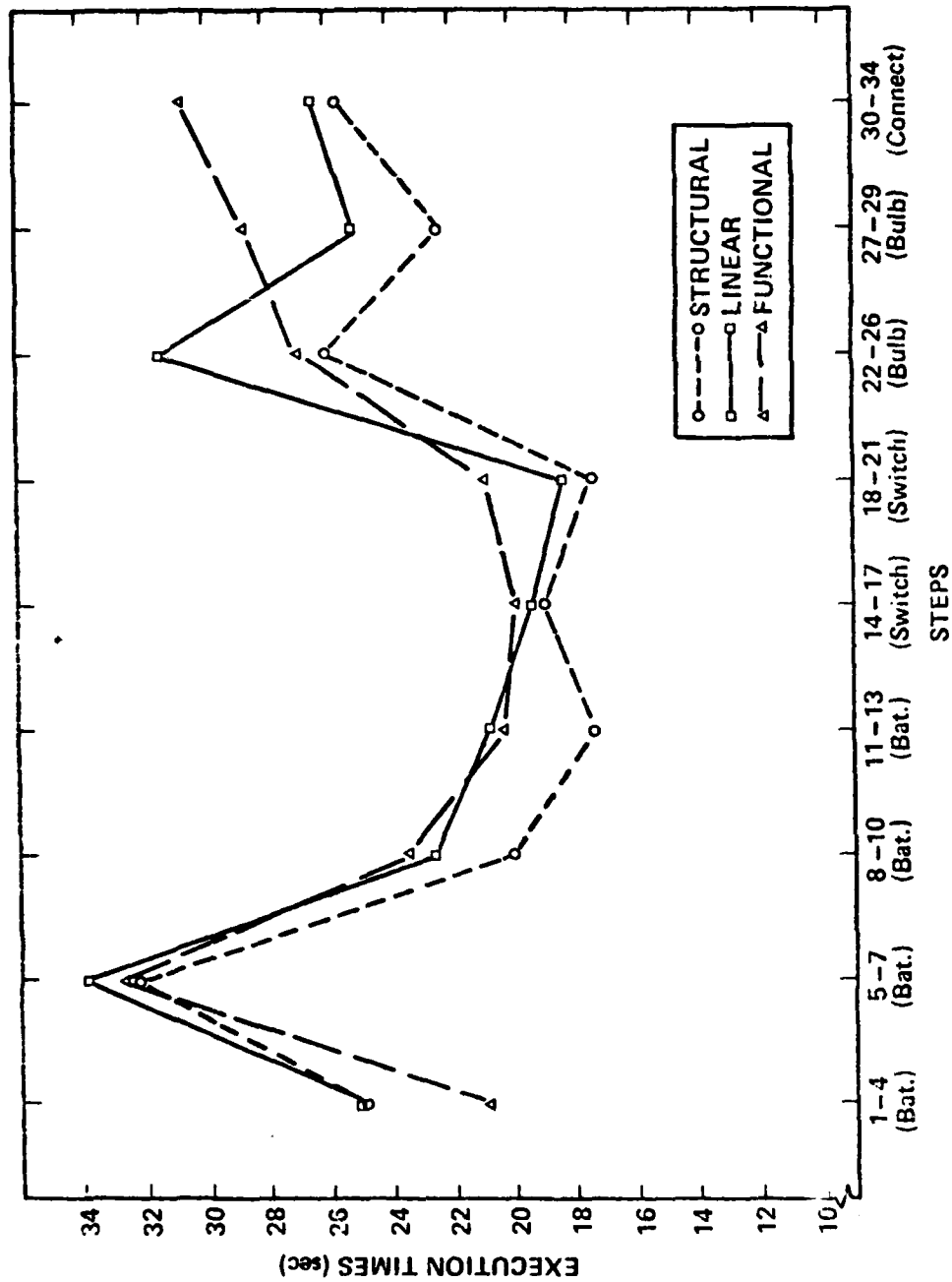


Figure 16. Execution times for chunks of steps (Experiment 2).

Table 7
Average Number Correct in Question-Answering Task
(Experiment 2)

<u>Type of Question</u>	<u>Type of Instructions</u>		
	<u>Linear</u>	<u>Structural</u>	<u>Functional</u>
Conceptual Understanding	.9	1.1	1.4
Trouble Shooting	1.7	1.7	2.1
Total	2.6	2.8	3.5

subject in the Linear group; her score was the highest in the entire experiment and virtually double that of the next best score in her group. When this subject was eliminated from consideration, along with the highest scores in the other two groups, the advantage of the Functional over the Linear group reached significance (3.3 vs. 2.0, $t(16)=2.41$, $p<.05$). The minor advantage of the Structural over the Linear group, however remained insignificant ($p>.10$).

3.6.4 Reconstruction

Subjects' reconstructions were scored with respect to the propositions in a step. For each step, we first determined which of its propositions could be scored for execution. To illustrate, consider Step 2 and its three component propositions:

(2) "Now you are to wrap one end of the wire around one of the short bolts."

(2a) WRAP (wire-end 1, bolt 1)

(2b) SHORT (bolt 1)

(2c) NOW (2a)

There was no point in scoring the subjects' reconstructions for Proposition (2c) since subjects always tried to execute a step at what they thought was the appropriate time. Propositions (2a) and (2b) were scorable; selection of a long rather than a short bolt, for example, would result in no credit for Proposition (2b). In most cases, though, if a subject got any of the scorable propositions in a step she got them all, i.e.,

reconstruction tended to be all or none with respect to the propositions in a step.

Figure 17 presents the percentage of propositions reconstructed for each chunk of steps, separately for the three instructional groups. These data differ from the recall results of the previous experiment in three respects. First, whereas Structural instructions led to the best recall, now they result in the poorest reconstruction, at least for the first half of the steps. (While the main effect of instructions failed to reach an acceptable level of significance, $F(2,27)=2.32$, $p>.10$, a selected contrast indicated that the Functional group performed significantly better than the Structural group, $F(2,27)=4.38$, $p<.05$.) Second, whereas Functional instructions led to better recall than Linear ones, the two types of instructions are equivalent with respect to reconstruction accuracy. Third, the shapes of the reconstruction functions are unlike those of the recall functions; at least for the Linear and Functional groups, reconstruction accuracy is generally quite high with relatively little variation due to steps.

3.7 Determinants of the Hierarchical advantage

In the previous study, we tried to determine the specific mechanisms responsible for the Hierarchical advantage in reading times and recall accuracy. Since the present study replicated only the advantage in reading time, we will concern ourselves only with this finding.

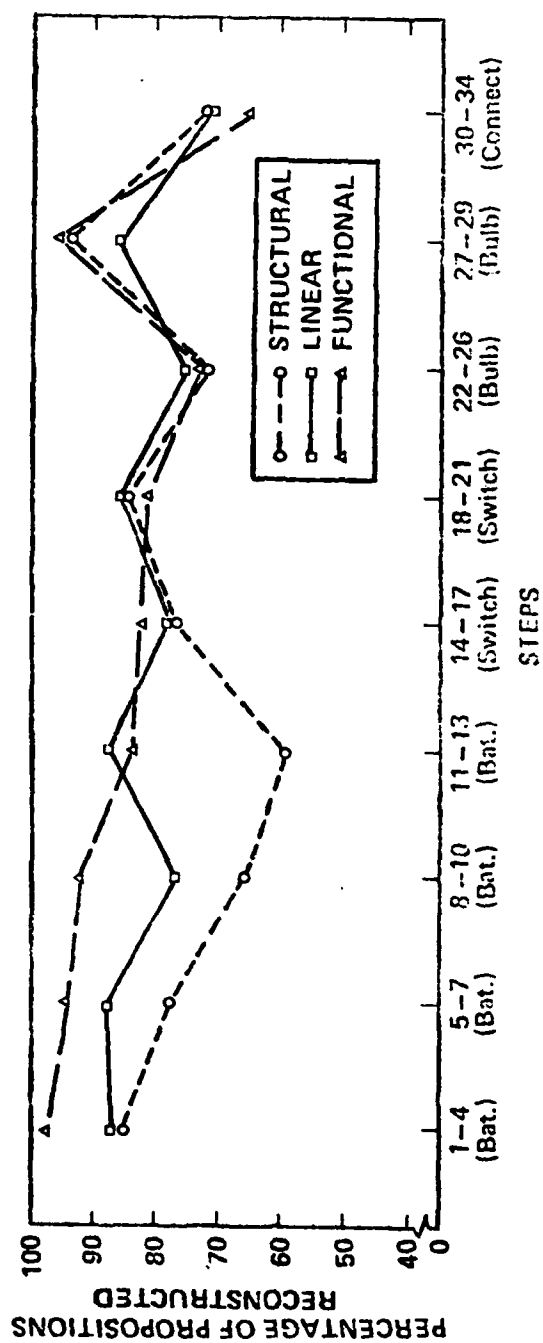


Figure 17. Percentage of propositions reconstructed (Experiment 2).

Again the hypothesis of interest is that the Hierarchical advantage in reading times is due to the concepts of some steps being preactivated by their prior mention in explanatory statements. We evaluated this hypothesis by determining whether the Hierarchical advantage -- the time to read a step in the Linear group minus the time to read the same step in the Structural or Functional group -- was greater for steps receiving prior activation than for those that did not. The relevant data are in Table 8. The reading-time advantages are a bit greater for steps that have been preactivated than for those that have not, but unlike the previous study the present differences do not approach significance. The fact that we obtained substantial reading-time advantages for the Hierarchical groups but minimal evidence for the role of preactivation indicates that the latter is not the sole cause of the former.

3.8 Results due to specific steps

Finally, let us briefly look at the effects of number of propositions and step type on reading times and execution times, to see how well we replicated the results of the previous experiment. (Since reconstruction is a different measure than verbal recall, the issue of replication does not arise here.)

3.8.1 Reading times

Figure 18 plots reading times as a function of number of propositions. As in the previous study, for all three

Table 8

Reading Time Advantages and Prior Activation
(Experiment 2)

	Linear-Structural	Linear-Functional
Activated	194 msec (N=22)	149 msec (N=18)
Non-Activated	154 msec (N=12)	118 msec (N=16)
All Steps	180 msec (N=34)	134 msec (N=34)

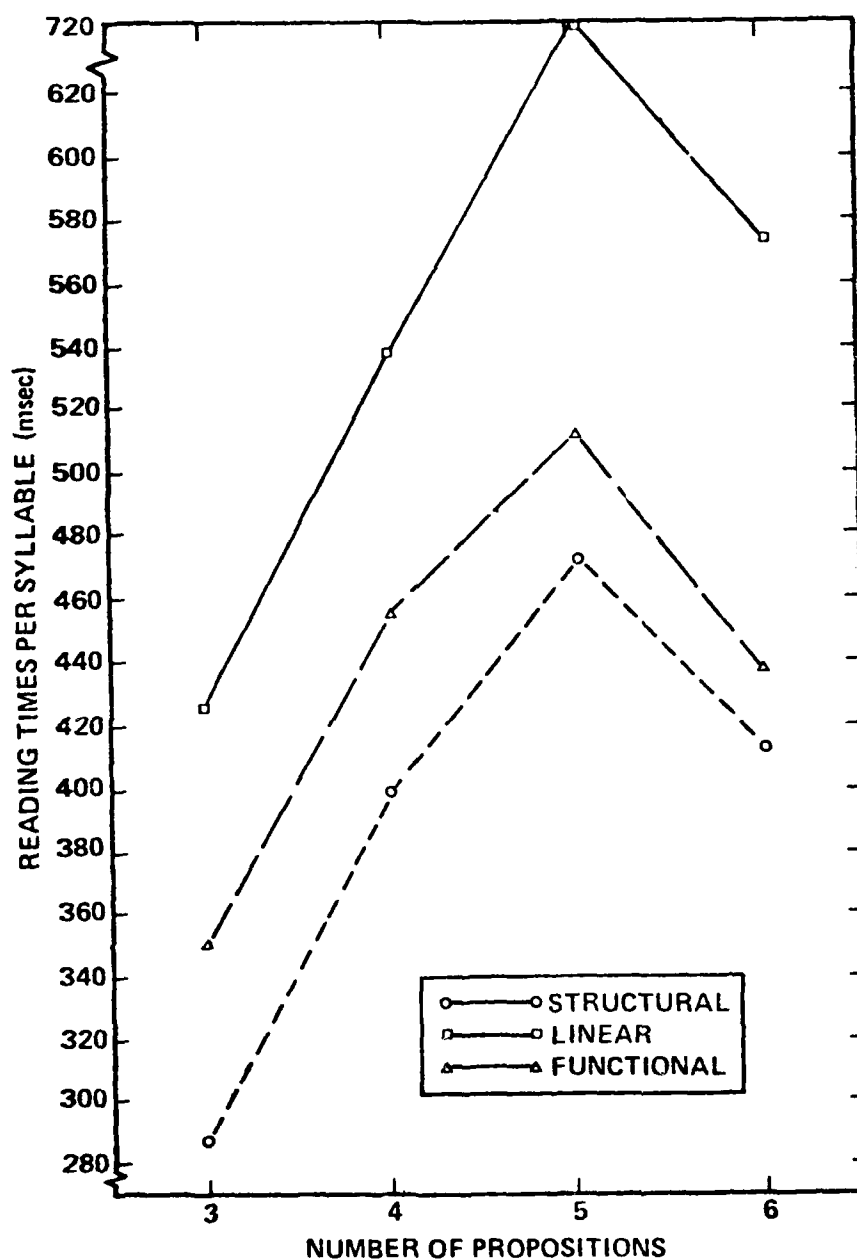


Figure 18. Reading times per syllable as a function of the number of propositions in a step (Experiment 2).

instructional groups, reading time increased from 3 to 4 to 5, and then decreased for 6 propositions ($F(3,81)=26.20$, $p<.001$). Figure 19 present the step-type effects. Once more the major results of the previous study were replicated as A and D steps took longer to read than B and C steps ($F(1,27)=33.44$, $p<.001$).

3.8.2 Execution times

The effect due to number of propositions is displayed in Figure 20. There is the usual significant and nonmonotonic effect of number of propositions ($F(3,81)=12.96$, $p<.001$). Similarly, Figure 21 indicates that we replicated our step-type effect as execution times were longest for B and D steps, and shortest for C steps.

3.8.3 Summary

We have completely replicated our earlier results: both reading and execution times generally increased as the number of proposition increased (at least up to 5), whereas reading and execution times were differentially affected by step type (reading time being sensitive to the importance of the step, and execution time being sensitive to the step's manual requirements).

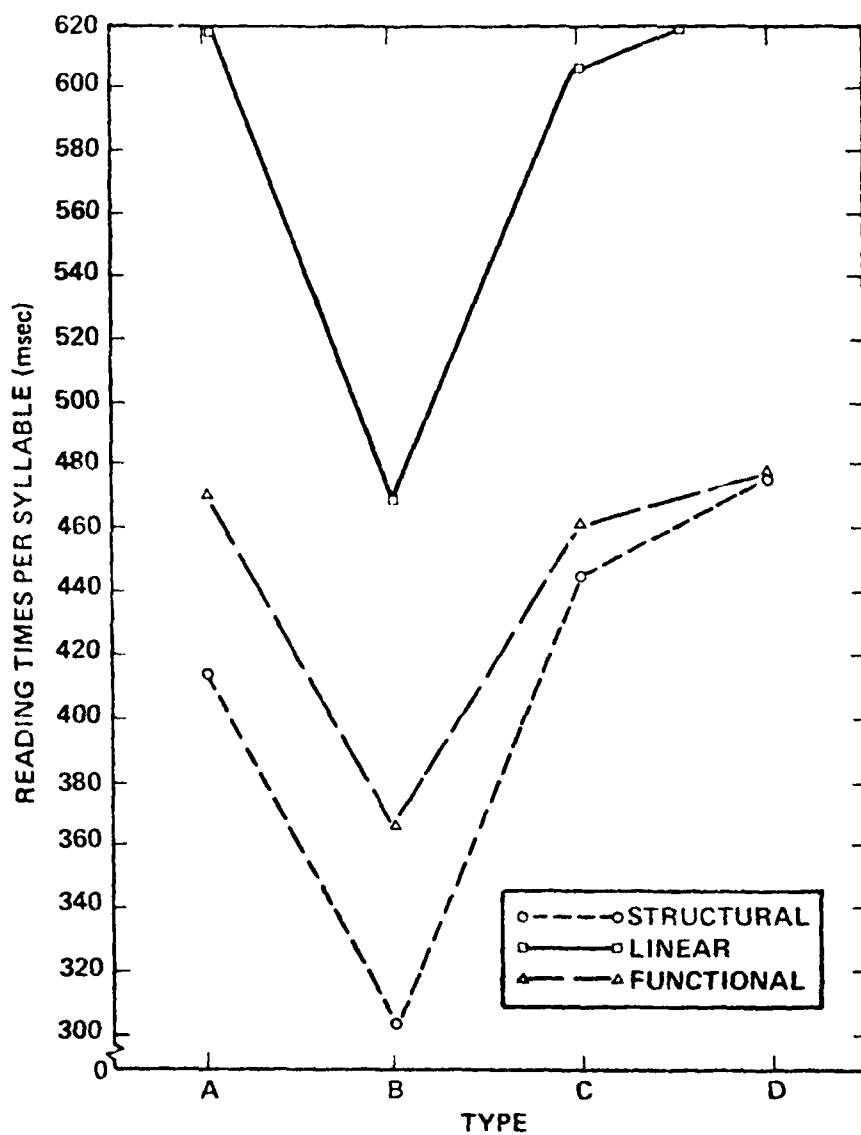


Figure 19. Reading times per syllable for each step type (Experiment 2).

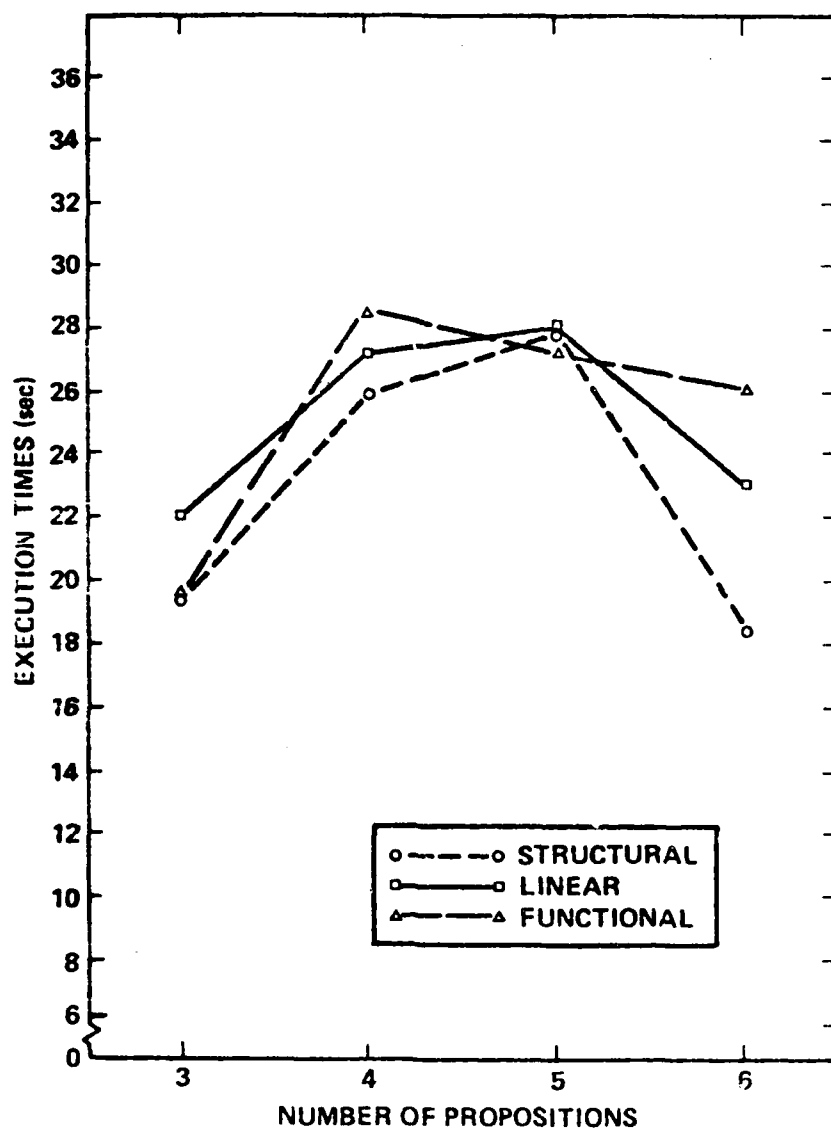


Figure 20. Execution times as a function of the number of propositions in a step (Experiment 2).

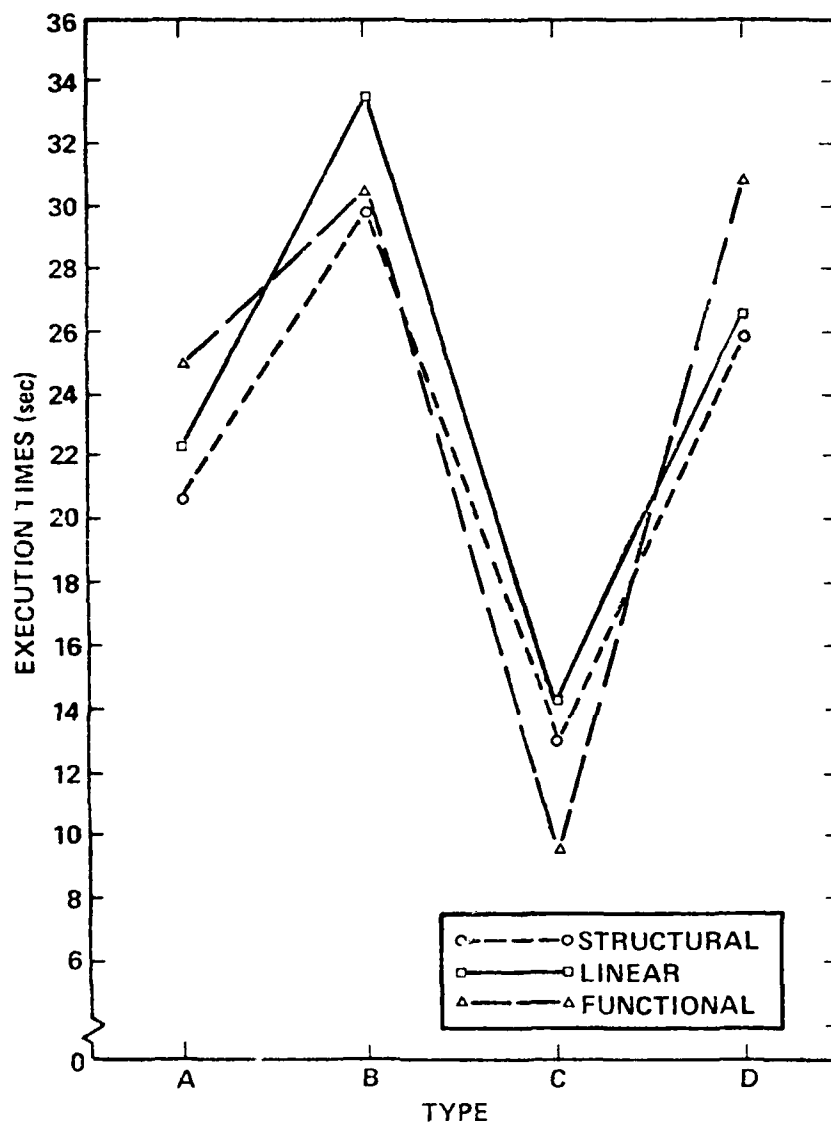


Figure 21. Execution times for each step type (Experiment 2).

4. CONCLUSIONS AND DISCUSSION

4.1 Benefits of explanatory material: Hierarchical advantages

Our major question has been whether the inclusion of explanatory material in assembly instructions improves the understanding, use, and retention of such instructions (where such improvements have been referred to as Hierarchical advantages). To answer this question, we have looked at six different dependent measures over the course of two experiments: (1) reading time (Experiments 1 and 2), (2) execution times (Experiments 1 and 2), (3) execution accuracy (Experiments 1 and 2), (4) question-answering (Experiments 1 and 2), (5) recall accuracy (Experiment 1), and (6) reconstruction accuracy (Experiment 2). On most of these measures we in fact obtained a Hierarchical advantage, indicating that the beneficial effect of explanatory material is very widespread. In what follows, we briefly review the case for each measure (treating related measures like (2) & (3) and (5) & (6) together), as well as consider what theoretical mechanisms might be involved.

4.1.1 Reading times

The Hierarchical advantages in reading times were extremely robust. Advantages obtained in both experiments, and within each study, were manifested on the vast majority of steps (e.g., in Experiment 1, 31 of 34 steps were read faster under Structural than Linear instructions). In addition to being robust, the

Hierarchical advantages were extremely large in magnitude. In Experiment 1, for example, the advantage of Structural over Linear instructions was approximately 125 msec per syllable while that of Functional over Linear instructions was roughly 100 msec per syllable; this translates into an advantage of about 2.9 seconds per step for the Structural instructions (there being roughly 23 syllables per step), and an advantage of 2.3 seconds per step for the Functional instructions.

What theoretical mechanisms lie behind these substantial effects? The only mechanism we considered in detail was that of preactivation: some steps contained concepts that had previously been mentioned in an explanatory statement, and these preactivated steps requiring less processing. While there was evidence that preactivation played a substantial role in Experiment 1, such evidence was lacking in Experiment 2. At best, then, preactivation as defined in these studies is only part of the story.

Perhaps a more precise notion of preactivation would fare better. The notion we have been using contains two distinguishable factors: (1) concept repetition, wherein the very same concept is expressed in an explanatory statement and in a subsequent step (e.g., the very same dry cells are referred to), and (2) concept instantiation, wherein a concept is expressed in an explanatory statement and an instantiation of it is later expressed in a step (e.g., an explanatory statement

mentions " . . . wire together . . .," and the very next step mentions ". . . the short red wire that has been stripped at both ends"). It is possible that only one of these factors is involved in the Hierarchical advantage in reading times, and inclusion of the other factor is just adding noise to our calculations. Indeed, there is good reason to believe that concept repetition is not critically involved in Hierarchical advantages: there is a substantial amount of concept repetition just among steps, which means this factor may provide little distinction between Hierarchical and Linear instructions. So, concept instantiation seems a better bet to be a critical factor.

The notion of concept instantiation is related to another possible account of Hierarchical advantages in reading times. This is the idea that when reading assembly instructions, people try to construct a representation that relates all steps, and it is easier to do this by adding explanatory material to the representation (thereby making it hierarchical) than by confining the representation to just steps. This idea is elaborated in Figure 22, which gives two partial representations of the first three steps of our assembly instructions. The representation on top is confined to steps. Therefore it must relate the steps by horizontal connections, where the latter may be quite unfamiliar. The second representation contains explanatory material. Consequently it can relate the steps by vertical connections, i.e., each step is an instantiation of a higher-level concept. Assuming that these vertical connections are more familiar or

Linear representation

Find wire → Wrap wire around one short bolt → Wrap wire around other short bolt

Hierarchical representation

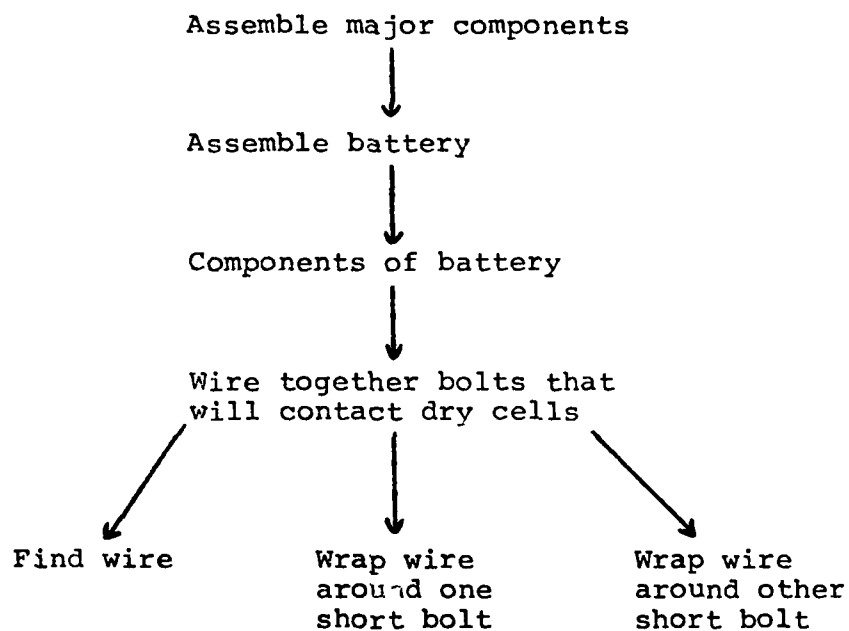


Figure 22. Two partial representations of the first three steps in circuit-assembly instructions.

somehow easier than the horizontal connections between steps, it follows that the Hierarchical representation is easier to construct than the strictly Linear one at the top of Figure 22. As we will see, this postulated difference in representations has implications for measures other than reading times.

4.1.2 Execution times and accuracy

Experiments 1 and 2 both failed to turn up any evidence for a Hierarchical advantage in execution times. This lack of an effect cannot be readily attributed to an insensitivity of execution times, for these times were sensitive to variations in the number of propositions and the type of step. Since the step type effect seemed to be mediated by the manual requirements of the step, it is possible that execution times are more sensitive to the motor end than to the cognitive end of instruction-following. In any event, we leave it a question for future research whether an instructional effect on execution times can be obtained under different circumstances.

Execution accuracy is another matter. On this measure we did find some evidence for Hierarchical advantages in Experiment 1. While the results were in the same direction in Experiment 2 -- fewer errors with Structural and Functional instructions than with Linear ones -- the differences were nonsignificant. Though these two sets of data offer rather limited support for Hierarchical advantages in execution errors, recall that the probability of such errors was minimized by various aspects of

our procedure (e.g., immediately informing subjects of their errors, helping them when they had motoric difficulties). It seems plausible that if we remove these procedural aids, many more errors will be committed during execution, and more robust Hierarchical advantages will manifest themselves.

What mechanisms might mediate such advantages? Again we appeal to the kind of Hierarchical representation illustrated in Figure 22. If subjects working with Structural and Functional instructions developed such a representation, they might be able to use some of the higher-level information (i.e., any node in the hierarchy above the level of a terminal step) as constraints on how to execute some of the terminal steps, and this would reduce the incidence of errors. That is, there is always some vagueness in the description that comprises an instructional step, and one can reduce this vagueness by bringing in constraining information from other sources, like explanatory material.

We can illustrate this idea with an example that actually occurred in our experiments. Step 14 said to put a washer on a short bolt. The description was vague in that it did not explicitly mention that the short bolt in question was to be an unattached one (this was the start of the switch assembly), rather than a bolt that was already part of the battery assembly. Some subjects in the Linear group mistakenly started to put a washer on one of the short bolts that was already attached to the

battery assembly. In contrast, no one in the Structural and Functional groups committed this error, presumably because they had earlier read an explanatory statement informing them that they had completed the battery assembly. The latter information provided an additional constraint to bring to bear on the issue of what short bolt Step 14 was referring to.

4.1.3 Questions answering

In Experiment 1, there was no Hierarchical advantage in question answering: all three instructional groups were roughly equally accurate in answering questions about the circuit. This lack of an effect appears to have been due to a poor selection of questions, for in Experiment 2, where more sensitive questions were used, there was some evidence for a superiority of the Functional instructions. The explanatory material about some basic electronics enhanced subjects' ability to reason abstractly about the circuit and to troubleshoot faulty renditions of the circuit.

The most obvious account of why Functional instructions boosted question answering lies in the kind of representation that such instructions would lead to. Not only would it be Hierarchical, but its higher-level nodes would contain information needed to reason about and troubleshoot the circuit. This much appears obvious. What seems of greater interest is the possibility that this higher-level information may have been transformed into a mental model for the circuit, and that

subjects essentially "ran" this model (a mental simulation) when answering the troubleshooting questions (e.g., Gentner & Stevens, 1982; Stevens & Collins, 1981).

4.1.4 Memory

Two different measures of memory were used in this research, verbal recall in Experiment 1 and reconstruction in Experiment 1. Since they produced such different patterns of results, we treat them separately in what follows.

4.1.4.1 Verbal recall

Experiment 1 revealed Hierarchical advantages in recall, as both the Structural and Functional groups recalled more steps than the Linear group. At a theoretical level, these results seem to be partly due to chunking. The explanatory material essentially divided the steps into chunks, where the psychological validity of these chunks was demonstrated by our finding of more all-or-none recall within a chunk than between a chunk for the Hierarchical groups.

One thing that remains to be determined is what specific aspects of the Hierarchical instructions created the chunks. At one extreme, one might argue that the explanatory material that preceded the steps (six or seven statements) had nothing to do with the creation of chunks; rather, the chunks were created solely by the explanatory statements that were interspersed among the steps, thereby literally dividing or grouping them. At

another extreme, one might argue that the chunks were a natural consequence of a Hierarchical representation like that in Figure 22, in that different chunks of steps correspond to different branches of the hierarchy. Under the latter view, all explanatory statements play a role in the creation of the chunks. Further studies are needed to distinguish between these positions.

Regardless of exactly how it comes about, chunking cannot be the whole story behind our observed variations in recall. For the chunking possibilities were virtually identical in the Structural and Functional groups, yet the former group recalled substantially more than the latter. A possible reason for this difference is that the Structural explanatory material was easier to understand than the Functional material (the Structural statements were read two seconds faster on the average); consequently subjects who had the Structural material had more time to rehearse the chunks of steps.

The preceding has focused on relatively low-level memory mechanisms, namely chunking and rehearsal. A complete account of Hierarchical advantages in recall may have to consider more complex mechanisms as well; e.g., complex search strategies that are tied to the higher-level nodes of Hierarchical representations.

4.1.4.2 Reconstruction

Experiment 2 did not turn up any Hierarchical advantages in

reconstruction accuracy. These null effects, however, may simply reflect the insensitivity of our particular reconstruction task, i.e., the accuracy of reconstruction was sufficiently high in the Linear group that there was little room to demonstrate an improvement with Functional instructions. Had we, say, introduced a longer time delay between initial assembly of the circuit and subsequent reconstruction, we might well have obtained an advantage of the Functional over the Linear instructions. This possibility needs to be explored in future research.

While there were no Hierarchical advantages, the reconstruction data did show that the Functional instructions were superior to the Structural ones. This result is striking, given the fact that Structural instructions led to better recall in Experiment 1. Taken together, these two results imply that reconstruction was not primarily guided by the retrieval of steps (else it would have produced similar results to recall); rather, reconstruction seems to have been partly guided by the explanatory material (if available), and Functional explanatory material appears to have been a better guide than its Structural counterpart.

4.2 Effects due to specific steps

Perhaps one of the most robust and striking findings to emerge from the current experiments is that there were effects on

numerous dependent measures due to specific steps that were relatively invariant over types of instructions. This demonstrates the need for an analysis of instructions at the level of specific steps.

Such an analysis can start with the two effects uncovered in the present studies: (1) performance generally declined with the number of propositions in a step, and (2) reading times and execution times depended in different ways on step type. In line with findings in other areas of text processing (e.g., Kintsch & van Dijk, 1978), we suspect that a theoretical account of the propositions effect will focus on working memory; e.g., the more propositions in a step, the more descriptions and procedures that must be kept active in working memory. A theoretical analysis of the step type effects will probably take even more work since this factor was explored in only a post-hoc fashion in the present studies. As mentioned earlier, our best guess is that at least part of the step-type effect reflects variations in importance, and that the reason why step-type produced differential effects is that reading and execution vary in the extent to which they tap conceptual understanding versus motoric performance.

Report No. 5088

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UNDERSTANDING INSTRUCTIONS: THE ROLE OF EXPLANATORY MATERIAL.(U)

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APPENDIX A
COMPLETE LISTINGS OF LINEAR, STRUCTURAL AND
FUNCTIONAL INSTRUCTIONS USED IN EXPERIMENT 1

Linear

- I. You will construct an electrical circuit that will light a small lamp when you press a switch.*
- II. The components of the circuit will be installed in the yellow plastic console.*
 1. Select the short red wire that has been stripped at both ends.
 2. Now you are to wrap one end of the wire around one of the short bolts.
 3. Next you are to wrap the other end of the wire around another one of the short bolts.
 4. Screw a nut on the end of each bolt until it catches the bolt's threads.
 5. Locate the two spaces for the dry cells on the console's underside; we'll call these spaces dry cell holders.
 6. These holders have a pair of posts with grooves; place the bolts in these grooves so the bolt heads face into the console.
 7. Tighten each nut, holding the bolt in place, ensuring the wire's ends remain hooked to the bolts.
 8. Now you are to screw a nut halfway up on each of the two long bolts.
 9. Place the bolts into the two grooves on the outer edge of the dry cell holder so the bolt heads face inward.
 10. You should tighten the nuts with your finger, but be sure not to make them too tight.
 11. Locate the positive and negative pole on opposite ends of each dry cell, marked + and -.
 12. Snap each cell into the holders so one cell's positive

pole, and the other's negative, point in the same direction.

13. Tighten the nuts on the long bolts, ensuring that each cell is firmly pressed against the bolts' heads.
14. You are to put a washer, which is made of cardboard, on a short bolt.
15. You are to insert this bolt in the hole that is numbered 62, doing this from the top of the console.
16. Now what you need to do is to screw a nut on this bolt from the underside of the console.
17. Again from the underside of the console, push a short bolt through the hole numbered 64.
18. Place the metal switch spring on this bolt, using the hole closest to the square end of the switch spring.
19. Position the free end of the switch spring over the bolt in hole #62.
20. You are to screw a nut onto the bolt that is holding the switch spring and make sure that the nut is tight.
21. Bend the spring's free end up slightly so that it does not touch the bolt head.
22. Now what you need to do is to place a washer, which is made of cardboard, inside the socket.
23. Push a short bolt through the washer and hole in the socket's bottom so the bolt head is inside the socket.
24. You are to insert the end of the bolt in the hole that is numbered 71 on the console.
25. From the console's underside, put a washer and nut on the bolt's end.
26. Ensure that the bolt head isn't touching the socket's sides.
27. Select the wire stripped on one end and fitted with a black plastic sleeve on the other.
28. Insert the stripped end into the hole on the socket's side so a 1/4 inch of wire curls within the socket.
29. Screw the bulb tightly into its socket, so the bulb's

end touches the bolt head.

30. Push the sleeve on the end of the wire from the socket onto the switch terminal bolt on the console's underside.
31. Using a wire with sleeves at both ends, push one of its sleeves onto the bolt in contact with the battery's positive pole.
32. Put the wire's other sleeve onto the end of the bolt holding the switch in place on the console's topside.
33. Put a sleeve from another wire onto the bolt in contact with the battery's negative pole.
34. You should now put the sleeve on the end of this wire onto the bolt holding the socket in place.
35. When you press the switch, you will see that the bulb now lights up.

Structural

- I. You will construct an electrical circuit that will light a small lamp when you press a switch.*
- II. The components of the circuit will be installed in the yellow plastic console.*
- III. Assembling a circuit requires that you get the major components ready, then connect them.*
- IV. It is often the case that the components themselves have to be assembled first.*
- V. The circuit has three major components:
(1) battery, (2) switch, and (3) small lamp.*
- VI. As a way of starting things off, we will first have you assemble the battery.*
- VII. In this case the main components of the battery consist of two dry cells.*
- VIII. And the minor components of the battery consist of wire, nuts and bolts.*
- IX. The first things that you will do is to wire together

two bolts that will be placed in contact with the dry cells.*

1. Select the short red wire that has been stripped at both ends.
2. Now you are to wrap one end of the wire around one of the short bolts.
3. Next you are to wrap the other end of the wire around another one of the short bolts.
4. Screw a nut on the end of each bolt until it catches the bolt's threads.
5. Locate the two spaces for the dry cells on the console's underside; we'll call these spaces dry cell holders.
6. These holders have a pair of posts with grooves; place the bolts in these grooves so the bolt heads face into the console.
7. Tighten each nut, holding the bolt in place, ensuring the wire's ends remain hooked to the bolts.
- X. Next you'll install two more bolts that will also be in contact with the dry cells.*
8. Now you are to screw a nut halfway up on each of the two long bolts.
9. Place the bolts into the two grooves on the outer edge of the dry cell holder so the bolt heads face inward.
10. You should tighten the nuts with your finger, but be sure not to make them too tight.
- XI. In order for you to complete the battery assembly, you need to insert the dry cells in the dry cell holders.*
11. Locate the positive and negative pole on opposite ends of each dry cell, marked + and -.
12. Snap each cell into the holders so one cell's positive pole, and the other's negative, point in the same direction.
13. Tighten the nuts on the long bolts, ensuring that each cell is firmly pressed against the bolts' heads.
- XII. The next thing that you will have to do is to assemble the on-off switch.*

XIII. The main components of the switch are a metal switch spring, and two contact bolts.*

14. You are to put a washer, which is made of cardboard, on a short bolt.
15. You are to insert this bolt in the hole that is numbered 62, doing this from the top of the console.
16. Now what you need to do is to screw a nut on this bolt from the underside of the console.
17. Again from the underside of the console, push a short bolt through the hole numbered 64.
18. Place the metal switch spring on this bolt, using the hole closest to the square end of the switch spring.
19. Position the free end of the switch spring over the bolt in hole #62.
20. You are to screw a nut onto the bolt that is holding the switch spring and make sure that the nut is tight.
21. Bend the spring's free end up slightly so that it does not touch the bolt head.

XIV. The next thing you will do will be to construct the small lamp.*

XV. The main components of the lamp are the bulb and its socket.

22. Now what you need to do is to place a washer, which is made of cardboard, inside the socket.
23. Push a short bolt through the washer and hole in the socket's bottom so the bolt head is inside the socket.
24. You are to insert the end of the bolt in the hole that is numbered 71 on the console.
25. From the console's underside, put a washer and nut on the bolt's end.
26. Ensure that the bolt head isn't touching the socket's sides.
27. Select the wire stripped on one end and fitted with a black plastic sleeve on the other.

28. Insert the stripped end into the hole on the socket's side so a 1/4 inch of wire curls within the socket.
29. Screw the bulb tightly into its socket, so the bulb's end touches the bolt head.
- XVI. You have assembled the circuit's major components and are ready to connect them.*
- XVII. The first connection you will make will be between the lamp and the switch.*
30. Push the sleeve on the end of the wire from the socket onto the switch terminal bolt on the console's underside.
- XVIII. The second connection you will make will be between the switch and the battery.*
31. Using a wire with sleeves at both ends, push one of its sleeves onto the bolt in contact with the battery's positive pole.
32. Put the wire's other sleeve onto the end of the bolt holding the switch in place on the console's topside.
- XIX. Finally, the last connection that you will make is between the battery and the lamp.*
33. Put a sleeve from another wire onto the bolt in contact with the battery's negative pole.
34. You should now put the sleeve on the end of this wire onto the bolt holding the socket in place.
35. When you press the switch, you will see that the bulb now lights up.

Functional

- I. You will construct an electrical circuit that will light a small lamp when you press a switch.*
- II. The components of the circuit will be installed in the yellow plastic console.*
- III'. In a circuit, electrical current flows from a source to a "consumer" (i.e., to something that requires current, like a lamp.*

- IV'. Current can flow only when the circuit's components are interconnected in a complete circle, each connection being made by a wire or other metal object that conducts electricity.*
- V'. This circuit's major components are a battery, the source of the current; a lamp, the main consumer; and a switch, which in ON position forms a connection that allows current to flow.*
- VI'. The battery itself consists of two dry cells, and it is these dry cells that are the source of the current.*
- VII'. The dry cells have to be connected so that current can flow from the negative pole of one cell to the positive pole of the other.*
- VIII'. The first thing that you will do is to make the wire connection that will later be used to link the two dry cells.*
 - 1. Select the short red wire that has been stripped at both ends.
 - 2. Now you are to wrap one end of the wire around one of the short bolts.
 - 3. Next you are to wrap the other end of the wire around another one of the short bolts.
 - 4. Screw a nut on the end of each bolt until it catches the bolt's threads.
 - 5. Locate the two spaces for the dry cells on the console's underside; we'll call these spaces dry cell holders.
 - 6. These holders have a pair of posts with grooves; place the bolts in these grooves so the bolt heads face into the console.
 - 7. Tighten each nut, holding the bolt in place, ensuring the wire's ends remain hooked to the bolts.
- IX'. Note that current can flow from one bolt holding the wire to the other, because bolts are good conductors and will be in direct contact with the battery.*
- X'. Next, you'll install two more bolts in the dry cell holders whose ends will later be attached to wires linking the battery to the bulb and switch.*

8. Now you are to screw a nut halfway up on each of the two long bolts.
9. Place the bolts into the two grooves on the outer edge of the dry cell holder so the bolt heads face inward.
10. You should tighten the nuts with your finger, but be sure not to make them too tight.
- XI'. To complete the battery, the dry cells must be placed in the holders so current can flow from one cell's positive pole, through the bolt and connecting wire, to the other cell's negative pole.*
11. Locate the positive and negative pole on opposite ends of each dry cell, marked + and -.
12. Snap each cell into the holders so one cell's positive pole, and the other's negative, point in the same direction.
13. Tighten the nuts on the long bolts, ensuring that each cell is firmly pressed against the bolts' heads.
- XII'. Next you'll construct the on-off switch by connecting a metal spring to two bolts.*
- XIII'. When completed, you will be able to close the circuit by pressing the spring against a bolt.*
14. You are to put a washer, which is made of cardboard, on a short bolt.
15. You are to insert this bolt in the hole that is numbered 62, doing this from the top of the console.
16. Now what you need to do is to screw a nut on this bolt from the underside of the console.
17. Again from the underside of the console, push a short bolt through the hole numbered 64.
18. Place the metal switch spring on this bolt, using the hole closest to the square end of the switch spring.
19. Position the free end of the switch spring over the bolt in hole #62.
20. You are to screw a nut onto the bolt that is holding the switch spring and make sure that the nut is tight.
21. Bend the spring's free end up slightly so that it does

not touch the bolt head.

- XIV'. The next thing you will do will be to construct the small lamp.*
- XV'. Current will flow through the lamp via a wire in from the battery and then out to the switch.*
22. Now what you need to do is to place a washer, which is made of cardboard, inside the socket.
23. Push a short bolt through the washer and hole in the socket's bottom so the bolt head is inside the socket.
24. You are to insert the end of the bolt in the hole that is numbered 71 on the console.
25. From the console's underside, put a washer and nut on the bolt's end.
26. Ensure that the bolt head isn't touching the socket's sides.
27. Select the wire stripped on one end and fitted with a black plastic sleeve on the other.
28. Insert the stripped end into the hole on the socket's side so a 1/4 inch of wire curls within the socket.
29. Screw the bulb tightly into its socket, so the bulb's end touches the bolt head.
- XVI'. The next thing you will do is to connect the three major components together in a circle so that current can flow around the circuit.*
- XVII'. The first connection you will make will be between the lamp and the switch.*
30. Push the sleeve on the end of the wire from the socket onto the switch terminal bolt on the console's underside.
- XVIII'. The second connection you will make will be between the switch and the battery.*
31. Using a wire with sleeves at both ends, push one of its sleeves onto the bolt in contact with the battery's positive pole.
32. Put the wire's other sleeve onto the end of the bolt holding the switch in place on the console's topside.

XIX'. Finally, the last connection that you have to make is between the battery and the lamp, thereby completing the circle.*

33. Put a sleeve from another wire onto the bolt in contact with the battery's negative pole.
34. You should now put the sleeve on the end of this wire onto the bolt holding the socket in place.
35. When you press the switch, you will see that the bulb now lights up.

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